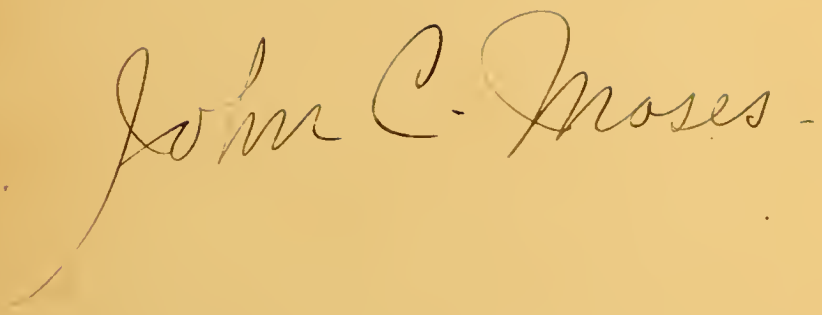
Class r 620.6

Book No. 31416

Northeastern University
Library


John C. Moses.

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXIX.

JULY TO SEPTEMBER, 1893.

NEW YORK:

PUBLISHED BY THE SOCIETY.

1893.

Entered according to Act of Congress, by the AMERICAN SOCIETY OF CIVIL ENGINEERS, in the Office of the Librarian of Congress, at Washington.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CONTENTS.

PAPERS.

NO.	MONTH.		PAGE
604	*July.*	Navigation Works Executed in France from 1876 to 1891. F. GUILLAIN	1
605	*do.*	Inland Transportation. F. A. MAHAN	97
606	*do.*	History of the Conversion of the River Clyde into a Navigable Water-Way, and of the Progress of Glasgow Harbor from its Commencement to the Present Day. JAMES DEAS	128
607	*do.*	Description of the Lower Weser and its Improvement. L. FRANZIUS	173
608	*do.*	A Brief Account of the Building of Leixões Harbor. ALFONSO JOAQUIM NOGUEIRA SOARES	194
609	*do.*	The Limits Attainable in Improving the Navigability of Rivers by Means of Regulation. H. ENGELS	202
610	*do.*	The Improvement of Harbors on the South Atlantic Coast of the United States. WM. MURRAY BLACK	223
611	*August.*	The Re-Arrangement of Railroad Tracks and Stations in Cologne, Prussia. F. LOHSE	277
612	*do.*	The Re-Arrangement of the Railway Terminal System at Altona, with Special Reference to the Avoidance of Grade Crossings. R. CAESAR	295
613	*do.*	Common Roads, Railways and River Communications in Portugal. FREDERICO AUGUSTO PIMENTAL	299
614	*do.*	The Railway System of New South Wales. THOMAS FLETCHER BIRRELL	326
615	*do.*	Railroads in the Republic of Mexico in 1893. E. PRIETO BASAVE	357
616	*do.*	Study upon Railroads to Connect Guadalajara with the Pacific Ocean. S. V. PASCAL	373
617	*do.*	Distinctive Features and Advantages of American Locomotive Practice. DAVID L. BARNES	385
618	*do.*	Comparison of Modern Engine-Loading with Standard Specifications for Spans from 10 to 200 feet. C. D. PURDON	426
619	*do.*	Surveys for Railway Location. F. A. GELBCKE	429
620	*do.*	A New Method of Calculating Cross-Sections of Roads and Railroads. FRANCISCO DA SILVA RIBEIRO	447
621	*do.*	On the Gauges of Railroad Track in General, with Special Consideration of Narrow-Gauge Railroads. E. A. ZIFFER	453

31416

NO.	MONTH.		PAGE
622	*August.*	Railway Signaling. G. KECKER	491
623	*do.*	Transmission of Power in Operating Cable Railways. ROBERT GILLHAM	543
624	*September.*	The Continuous Superstructure of the Memphis Bridge. GEORGE S. MORISON	573
625	*do.*	Bridge Superstructure and Foundations in Nova Scotia. MARTIN MURPHY	620
626	*do.*	Improved Method of Constructing Foundations Under Water by Forcing Cement into Loose Sand or Gravel by Means of Air Pressure. FR. NEUKIRCH	639
627	*do.*	American Grain Elevators. E. LEE HEIDENREICH	644
628	*do.*	The Manufacture and Use of Paving Brick. DANIEL W. MEAD	653
629	*do.*	Carbon and its Uses in Electrical Engineering. CLARENCE M. BARBER	680
630	*do.*	The Guadalajara Electric-Light Installation, Utilizing the Famous Juanacatlan Water Falls, 28 Km. Distant from Guadalajara. RAFAEL M. DE AROZARENA	689
631	*do.*	The Relative Merits of Working Hoisting Machinery by Steam, Water and Electricity. GEORGE A. GOODWIN	695
632	*do.*	Practical and Æsthetic Principles for the Laying Out of Cities. J. STÜBBEN	718

ILLUSTRATIONS.

PLATE.	MONTH.		PAPER	PAGE
I-III.	*July.*	River Clyde and Glasgow Harbor	606	171
I-V.	*do.*	Improvement of Lower Weser	607	193
I.	*do.*	Building of Leixões Harbor	608	201
I-VIII.	*do.*	Improvement of Harbors	610	276
I-VIII.	*August.*	Railroad Tracks and Stations in Germany,	611	292
I-II.	*do.*	Railway Terminal System at Altona	612	296
I.	*do.*	Railway System of New South Wales	614	354
I.	*do.*	Railroads in the Republic of Mexico	615	370
I-II.	*do.*	Comparison of Modern Engine Loading	618	426
I-IV.	*do.*	Transmission of Power for Cable Railways	623	570
I-XIX.	*September.*	Superstructure of Memphis Bridge	624	618
I-X.	*do.*	Bridge Superstructure in Nova Scotia	625	636
I.	*do.*	Method of Constructing Foundations Under Water	626	642
I-IV.	*do.*	American Grain Elevators	627	650
I.	*do.*	Manufacture and Use of Paving Brick	628	678
I-IV.	*do.*	Electric-Light Installation, at Guadalajara,	630	692

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

604.

(Vol. XXIX.—July, 1893.)

NAVIGATION WORKS EXECUTED IN FRANCE FROM 1876 TO 1891.

By F. GUILLAIN, Inspecteur-Général des Ponts et Chaussées, Directeur des Routes, de la Navigation, et des Mines au Ministère des Travaux Publics.

Translated from the French by C. L. CRANDALL, M. Am. Soc. C. E., assisted by C. W. SHERMAN, Jun. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The work presented in the following memoir is a collective work—that of the engineers of the Corps des Ponts et Chaussées, who are the engineers of the French government. It has been prepared with the concurrence of the chiefs of the principal departments of river and maritime navigation in France. The writer has had besides, as colaborers—for the technical description of the interior navigation works, M. Holtz, Inspector-General, Professor of Internal Naviga-

NOTE.—Discussion on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

tion at l'École des Ponts et Chaussées ; for the technical description of the maritime works, M. Quinette de Rochemont, Inspector-General, Professor of Ports at the same school ; for the financial and statistical part, M. Beaurin-Gressier, Chief of the Division of Navigation in the Department of Public Works.

The subject comprises two distinct parts—first, interior navigation works ; second, maritime navigation works.

There has been no effort made to give a detailed description of all of the navigable routes of France, and of the numerous maritime ports which serve for its traffic by sea ; nor to retrace the history of the composition of the system and of the installation of the ports. This description and this history have already been presented in numerous and voluminous works, some of which will appear at the exposition connected with the International Congress of Civil Engineering.*

It appears to the writer that it would be interesting to bring out the principal improvements of a technical or economic order executed in recent years upon our navigable routes and ports ; to give at least a rapid glance at all of them ; to indicate the nature and the cost of these improvements, their influence upon the development of traffic, the new facilities of all sorts assured to circulation, and the reductions obtained in the cost of transportation.

This programme adopted, it is only necessary to fix the beginning of the period to be considered, which has been taken at the year 1876. This year corresponds in France to a marked return of interest in navigation. It is from this year that a certain number of laws date which authorize the execution of important works, and that interest increased in the following years. A vast programme of improvements of rivers, canals and ports was brought forward in 1878. This resulted in 1879 in two important bills (July 29th, for maritime ports; August 5th, for navigable routes), which divided water-ways and ports into several classes, and determined for each the technical conditions which should be followed.

The choice of the year 1876 for the starting point permits the consideration of a period of 16 years which terminates at the begin-

---

* Guide officiel de la Navigation intérieure. 1892. Baudrey et Cie., éditeurs.

Statistique de la Navigation intérieure. Relevé du tonnage. 1892. Impie. Natale.

Statistique de la Navigation intérieure. Dépenses d'établissement et d'entretien. Documents historiques et statistiques. 1892. Impie. Natale.

Ports maritimes de la France. Texte et Atlas. Impie. Natale.

ning of the year 1892. The length of this period is sufficient to include the necessary delays in the preparation and execution of projects, and one can at least ascertain the first results. The enterprises begun in this period are not all completed. The original plans have, in fact, been modified by cutting down or adding to. But a considerable and very important part of the work in progress in 1876, in 1879, and in the following years is to-day completed, and has commenced to bear fruit. One can thus study the results of the effort, and give an account of the influence of the works undertaken upon the economic conditions of the regions traversed.

INTERIOR NAVIGATION WORKS.

Section I.—General Statement.

For the proper understanding of the explanations which are to follow, let us at first recall how the network formed of the principal lines is made up, at least all that part of it upon which the work of improvement for the last dozen years has been expended.

The lines upon which the traffic is the most important are concentrated in the regions of the north, of the center, and of the east. The first place belongs by right to the Seine, which flows through Paris, the capital of the country. This river constitutes, of itself, a great line of navigation. Down stream it connects Paris with the sea, at the ports of Rouen and of Havre. Up stream, it forms as far as Montereau the trunk of two great lines leading toward the basin of the Rhône and the Saône. One of these lines, passing through Burgundy, follows the Yonne (85 km.) as far as La Roche, then the canal of Burgundy (242 km.), and joins the Saône at St. Jean de Losne. The other, passing through Bourbonnais, follows the canals of the Loing (50 km.) and of Briare (59 km.), the canal along the Loire (193 km.), the canal of the center (116 km.), and joins the Saône at Châlons-sur-Saône.

Below Paris, the Seine connects with the system of navigable waterways of the region of the north. The principal branch of this system includes 283 km., formed of the Oise canalized, the canal by the side of the Oise, the canal of St. Quentin, of a part of the Escaut and of a part of the canal from Mons to Condé. It is prolonged by two branches, one of which, very important, extends toward Charleroi and is formed of the Sambre and of the canal from the Sambre to the Oise (125 km.), while the other extends towards Tournay (15 km.).

From the principal line connecting Paris with Belgium there branch: first, the canal of the Somme (156 km.), starting from St. Simon, on the canal of St. Quentin, to connect with the port of St. Valéry, in Manche; then the special system of the departments of the North and of Pas-de-Calais, the numerous branches of which serve the industrial centers of this region, while their principal extremities extend to the Belgian frontier, and to the ports of Dunkirk and Calais.

Above Paris, the Seine is connected by the Marne with a line leading to the eastern frontier, comprising the Marne (179 km.), the canal along the Marne (63 km.), and the canal from the Marne to the Rhine (210 km.).

In the east, a great line 432 km. long extends from the north to the south, under the name of Canal of the East. It starts from Givet (Belgian frontier) and joins the Saône at Corre. From this last line one can follow the Saône, which receives the two lines from Paris to Lyons by Burgundy and Bourbonnais, to its junction at Lyons, a distance of 374 km.; then the Rhône from Lyons to the Mediterranean, 334 km. In order to complete the description of the principal features of this part of the French system, there should be mentioned the water-ways joining the lines from Paris to the Belgian frontier, from Paris to the German frontier, and the Canal of the East, These are: the canal of Ardennes (88 km.), the canal along the Aisne (51 km.), that from the Aisne to the Marne (58 km.), and the canal from the Oise to the Aisne (48 km.); finally, as new routes, still incomplete, the canal from the Marne to the Saône, which will be 153 km., and the canal from the Doubs to the Saône, which will be 82 km.

A certain number of secondary lines of the east and of the center are omitted from this enumeration. The rest of the system comprises, in the south, the lines connecting the Mediterranean with the ocean; in the southwest, the water-ways of the basins of the Garonne, of the Dordogne, and of the Adour; in the west, the water-ways of the basins of the Charente and of the Sèvre; in the northwest, the canals of Brittany, and a certain number of water-ways in secondary basins of little importance. Upon these last lines, and except the work executed at the mouths of our large rivers, there has been, from 1876 to 1892, no work of transformation of sufficient importance to receive a place in the present study. The actual length of the water-ways in habitual use in the French system is a total of 12 327 km., viz.: rivers, 7 522

km.; canals, 4 805 km. Nearly all of these routes are administered by the State; those operated privately include a length of only 858 km.

After the few years of rest which followed the war of 1870, France undertook the work of developing its routes of transportation. During the 20 years preceding, the railroads had been in almost exclusive favor, to the detriment of the water-ways. Since 1871, the services which rivers and canals would be able to render have been better understood, and the work of completing and perfecting the system of water-ways has been resolutely undertaken.

The first works which were organized were those for the establishment of the Canal of the East, and for the canalization of the Saône, prescribed by two laws of March 24th, 1874; a considerable work designed to re-establish the continuity of the lines intercepted by the new frontier, and which was only completed in 1887. The first of these cost over 100 000 000 francs. Construction work was soon after begun upon the Saône on a dam at Mulatière in the Lyons slack-water level (Decree of March 12th, 1875), and in the north, the improvement of the routes in the valley of the Aa was begun, in order to secure a depth of 2 m. Studies were pursued at the same time at other points, which resulted, in 1876, in the presentation to Parliament of several important projects. Let us mention the principal ones, in the order of the dates of the votes on the laws which resulted:

Creation of a depth of 3.20 m. upon the Seine, between Paris and Rouen (law of April 6th, 1878);

General improvement of the Rhône, between Lyons and the sea (law of May 13th, 1878);

Establishment at Paris of landing places (*bas ports*) and quays (law of June 7th, 1878);

Creation of depth of 2 m. upon the Seine, from Paris to Montereau (law of June 13th, 1878);

Creation of a depth of 2 m. upon the Yonne, from Montereau to La Roche (law of June 13th, 1878);

Improvement of the canal of Burgundy, having for its object an increase of the depth of the water, the lengthening of the locks, the raising of the bridges, increasing the water supply, etc. (law of June 13th, 1878).

Having arrived at this point of the work of transformation, the discerning public believed that before going farther it would be profit-

able to so modify the programme of the work to be done as to include the completion of the system, and, above all, to give to the different lines constructed heterogeneously during the preceding period, a unity of design which should materially increase the facilities of transportation. The programme thus modified was sanctioned by the law of August 5th, 1879. It had for its object the improvement, unification and completion of the system. It determined, as a whole, the classification of navigable ways, the régime to which they should be submitted, as well as the technical conditions of establishment. It divided them into two classes, principal lines and secondary lines. The first were those which served the general interests of the country. It was stipulated that they should be administered exclusively by the State. The others, of less importance, could be conceded for a limited time, with or without subsidies, to public societies, to associations, or to individuals.

The law fixed the dimensions of all the principal lines as follows: Depth of water, 2 m.; width of locks, 5.20 m.; length of locks measured between the chord of the lift-wall and the hollow quoins of the tail gates, 38.50 m.; clear height under bridges, 3.70 m. These dimensions are necessary over the entire territory, in order to insure the circulation of boats of 300 tons, of the type most common in France, that of the Flemish canal-boat. But these are only minima, and the law has placed no obstacle in the way of the adoption of larger dimensions, especially upon rivers and streams where boats can be used particularly appropriate to river navigation.

As to secondary lines, they have not been subjected to these rules; but in practice, it is sought to have them conform to them as far as possible, though it is not imperative.

The law contained the nomenclature of navigable ways, which determined the character of principal lines, and established the principle upon which the few concessions of these lines still existing should be extinguished. Such is the general character of the law of August 5th, 1879, which has given a strong impulse to interior navigation works, by directing them toward a definite end.

From 1876 to 1892 the labor of completion and of unification of the system was definitely carried out on 688 km. of new water-ways and 3 969 km. of improved water-ways, or omitting the water-ways upon which the works have not yet been completed, and from the estab-

lishment or improvement of which commerce has not yet been benefited, there remains 625 km. of new water-ways and 3 326 km. of improved water-ways.

Following the order of the preceding observations, we will now review the principal results which have been developed, taking up first the technical details and then the cost and traffic.

Section II.—Technical Considerations.

Chapter 1.—Construction of New Water-Ways.

The new works opened or undertaken since 1876 are the following:

	Kilometers.
Canal of the East, and branches	432
Canal of the Upper Marne, and Vassy branch	100
Canal from the Oise to the Aisne	48
Canal from Lens to the Deule	8
Tourcoing Branch	2
Canal from the Marne to the Saône (under construction)	153
Canal from the Doubs to the Upper Saône (under construction)	82

The works of the Canal of the East and those of the Canal of the Upper Marne were commenced at the beginning of the period considered in this study. The works of construction of the other canals were only begun after the vote of the programme of 1879. All the works comprised in the preceding list, with the exception of the canal from the Marne to the Saône, and of the canal from the Doubs to the Saône, are open to navigation.

Canal of the East.—The great navigable route thus designated had been conceived previous to the programme of 1878, and was decided upon after the war of 1870, with its principal object the re-establishment upon French territory of the communications intercepted by the new frontier. It traverses the east of France in a direction from north to south from Givet, where it forms the prolongation of the Belgian Meuse to Corre, and there joins the canalized Saône. It thus constitutes a water-way as direct as possible between the basin of the Meuse and that of the Rhone, between the North Sea and the Mediterranean.

It is made up of two principal branches, called the Northern branch and the Southern branch. The first starts at Givet, near the Belgian frontier, and ascends the valley of the Meuse, sometimes in the river,

sometimes as a lateral canal, as far as the canal from the Marne to the Rhine; its length is 272 km. Thence for a length of 22 km. it coincides with the canal from the Marne to the Rhine, previously constructed, and passes by the tunnel of Toug from the valley of the Meuse into that of the Moselle.

At Toul the southern branch begins and first follows the canalized Moselle; it then extends by canal to the divide and crosses the summit of the Vosges at an altitude of 361 m. above the level of the sea. Its length is 147 km. Two branches, one of 10, the other of 3, km. in length, extend to the cities of Nancy and of Epinal left to one side by the main line. Its total length, including the branches, is then 432 km.

In the parts in the river, the movable dams are trestle and needle dams of the Poirée system. Here are 175 locks having the regulation dimensions fixed by the law of 1879. Upon the north branch the water supply is naturally secured by a feeder direct from the Meuse. In the part from the Marne to the Rhine the supply is secured by powerful hydraulic engines, which are operated by the falls of the dams of the canalized Moselle above Toul. The power thus utilized varies according to the stage of the river, from 400 to 600 H. P., and the height of lift is 40 m. The water is forced up in cast conduits following the line of greatest declivity of the slope. These open into channels which have a total length of 13 km., and include two large cast-iron siphons and a tunnel. On account of the permeability of the soil, they are lined with concrete for a part of the distance.

A part of this water is again taken at Vacon and lifted anew by a steam pump to a height of 40 m., for the special supply of the summit level of the canal from the Marne to the Rhine. It reaches this level by a channel 8 km. in length, 7 km. of which are in an open masonry channel, and 900 m. in a siphon of cast-iron pipe. The volume of water raised yearly by the first group of engines is, on an average, 5 000 000 cu. m., and of the second, 3 000 000 cu. m.

The summit level of the south branch and the two levels next the summit, one each side, take their water from a reservoir constructed at Bouzey, which has a capacity of 5 000 000 cu. m., and is filled by the rainfall on its drainage area and by a feeder 42 km. long from the Moselle at Remiremont.

As to the Nancy branch, which constitutes by itself a small canal at the junction of the Moselle and Meurthe, it is supplied exclusively by

means of hydraulic engines, which are worked by the combined fall of two locks, and which pump the water of the Moselle to the summit level. The same engines supply the city of Nancy.

The different machines constructed for the water supply of the Canal of the East and of the canal from the Marne to the Rhine have worked for several years with perfect regularity, and they must be regarded as the newest and most original features, while at the same time they have been the most successful of any on this entire work.

The total cost of the canal reached in round numbers 100 000 000 francs. The labor lasted eight years, from 1874 to 1882. This considerable work was designed and carried to its completion by the late M. l'Inspecteur-Général des Ponts et Chaussées, Frécot, whose name remains inseparable from that of the Canal of the East.

Canal from the Oise to the Aisne.—This canal was included in the programme of 1879. It branches from the canal along the Oise near Chauny, ascends the valley of the Ailette, an affluent of the Oise, crosses the ridge separating the basins of the Oise and Aisne by the aid of a tunnel 2 365 m. long, and joins the canal along the Aisne near the lock of Bourg, by way of the valley of Braye-en-Laomois. Its length is 48 km. Its object is to improve the water communications between the north and the east of France ; it effects a saving in distance of 58 km. over the old routes, and does away with 60 km. of precarious river navigation, and thus assures economy and regularity in transportation in one of the directions of most importance.

There are 13 locks. The supply of the summit level, and of its two levels down to the first feeders, as upon the Canal of the East, is by means of powerful hydraulic engines. These are turbines, which pump the water to a height of 16 m., worked by water from a feeder established in the Aisne, and which embody all the improvements that have been brought out during the last 25 years in this sort of construction. This method of supply is supplemented by a small reservoir of a capacity of 1 000 000 cu. m., designed to help in filling the canal after it has been emptied, or to aid in the different contingencies which may arise during operation.

The tunnel of Braye, by which the canal crosses the ridge, presented exceptional difficulties in its execution. It is driven entirely through the lower strata of the *Suessonien*, but, at the entrance, on the slope of the Oise, the beds of clay form a pocket with the bottom

about 300 m. from the entrance. At this point, the accumulated water brought with it fine sand which covered the clay and rendered all work in the open air impossible. In order to overcome this, it was necessary to make use of compressed air; but then other difficulties arose. The compressed air induced the combustion of the lignite which was mixed with the clay and caused grave accidents, one of which cost the lives of 17 workmen. Thanks to the opening of a vertical shaft, and to energetic means of ventilation, they were able to continue and complete the work in the midst of the double danger of fire and flood. The expense per linear meter in the part constructed in compressed air has reached 6 720 francs. The canal was opened to navigation in 1890, and its tonnage rose in the very first year to 1 100 000 tons.* Its total cost of construction was, in round numbers, 35 000 000 francs.

Canal of the Upper Marne and from the Marne to the Saône.—Under different names, these two canals constitute only a single navigable route, designed to put the industrial regions of the north in communication with the basin of the Rhône by a more direct line than that which connects them to-day. The first part, 77 km. long, ascends the valley of the Marne alongside of the river from Vitry-le-François to Rouvroy. It was under construction from 1865 to 1879, and was put in complete operation in 1880. It is supplied by feeders from the Marne, and contains 33 locks. The cost exceeded 17 000 000 francs.

The second part, which has received the name of canal from the Marne to the Saône, forms a prolongation of the preceding. It starts at Rouvroy, the extremity of the canal of the Upper Marne, and continues to ascend the valley of the Marne as far as Langres; it then crosses, near this city, the ridge separating the basins of the Marne and Saône by a tunnel 4 825 m. long, and descends by the valley of the Vingeanne to its confluence with the Saône near Pontailler. Its total length is 153 km. The works, undertaken in 1879, are fully under way; the summit level, including the tunnel, is finished, but its adjacent levels still present two gaps of a total length of 55 km.

This canal comprises numerous structures, among which may be mentioned several aqueducts across the Marne, and the great tunnel through the ridge, one of the most important which has been constructed for the passage of a navigable water-way. The grade is overcome upon the slope towards the Marne by 40 locks; and was to have

* The ton used throughout this paper is the French *tonne* of 1 000 kg., or 2 204 lbs.—*Trans.*

been overcome upon that towards the Saône by 44 locks and 2 elevators; but locks with high lifts in construction were substituted for these latter.

The supply is assured, in the lower portion of the canal, by feeders from the Marne and the Vingeanne, and in the upper part by four reservoirs, capable of impounding 45 000 000 cu. m. Two of these reservoirs, that of Liez and that of Mouche, have been constructed. The first has an available capacity of 15 400 000 cu. m. Its embankment of earth has a maximum height of 14.4 m., and has been constructed according to the usual French method, by means of a homogeneous puddle core, formed of a mixture of sand and clay, and thoroughly compressed by a steam-roller.

The second reservoir has a capacity of only 8 700 000 cu. m.; but the height of the walls reaches 22.50 m. above the bottom sluice gates, and the dam is of masonry. It has been constructed according to the profile approved in France by the examples of the large reservoirs of Furens, of Ternay, of Ban, of Chartrain, that is to say, starting with vertical faces, and changing to a light batter on the up-stream side, and a strongly inclined curved face on the down-stream side, so as to offer the necessary resistance at the base, and in each of the horizontal or oblique sections. The thickness was determined by the methods of MM. Delocre and Bouvier, with the modifications which have been added since by M. Guillemain. The top of the wall carries a road supported by arches projecting on the lower face; this happy arrangement gives it a decidedly architectural appearance.

The total cost of the works on the canal from the Marne to the Saône is estimated at 80 000 000 francs, of which about 55 000 000 francs have already been expended.

Canal from St. Dizier to Vassy.—This canal connects with that of the Upper Marne, but is only a branch designed to serve the smelting establishments of the valley of the Blaise. Its length is 23 km.; it was constructed between 1880 and 1883, and is to-day in full operation. It is supplied by the waters of the Blaise and by a small reservoir of 2 000 000 cu. m. capacity. Classed with the secondary canals, it has been let to a company which carries it on by means of a toll. The expense of 5 200 000 francs has been met, two-thirds by the State and one-third by the company to which it was conceded.

Canal from Montbeliard to the Upper Saône.—The last-built navigable

water-way to be mentioned is the canal from Montbeliard to the upper Saône, which will complete, with the Canal of the east, the restoration upon French soil of the communication intercepted by the new frontier, and serve, besides, the coal mines of Ronchamps.

Like all the preceding, with the exception of the Vassy canal, it is classed with the principal lines which the State constructed on the strength of its budget, and which it should itself administer. The works are much less advanced and have been carried on exclusively up to date upon the summit level, by means of which this canal will cross the ridge separating the basins of the Doubs and of the Saône, and upon the large supply reservoir with a masonry dam, situated in the neighborhood of this level. Under this head the expenses have already risen to 10 000 000 francs.

Chapter 2.—Improvement of Existing Water-Ways.

The preceding description shows the importance of the works in progress since 1868, which are required to fill up the gaps that the system of navigable ways in France still presents. All the lines recently constructed correspond, moreover, in their technical requirements, to the regulations prescribed by the law of August 5th, 1879. But by far the greatest part of the task accomplished since that date has consisted in the improvement of existing routes. Their depths have been increased to a minimum of 2 m., the locks have been reconstructed, placing the width at 5.20 m. and the length at 38.50 m., and the sources of supply have been increased to satisfy the new requirements. This work was done while the ways were in full operation, at the same time reducing as much as possible the delays and restrictions to navigation caused by the work in progress.

This work is to-day nearly completed, at least upon the principal lines. It has brought up difficult problems, exercised the sagacity of the engineers, and imposed expenses greater than those which have been contracted in the same period in the construction of new lines. The length of navigable ways on which a depth of 2 m. exists at all times has reached 4 787 km. The rivers and canals, of which the locks have at least the regulation dimensions, represent a total length of 3 956 km. Finally, the improved routes which fulfill the two conditions necessary for giving passage at all times to boats 38.50 m. long and drawing 1.80 m., include a length of 4 014 km.

The following table gives the situation in 1878 and at the present time :

Total length of navigable water-ways having a minimum depth of 2 m., and locks of 38.50 x 5.20 m.

	Rivers.	Canals.	Total.
	Kilometers.	Kilometers.	Kilometers.
Situation in 1878	996	463	1 459
Present situation	1 934	2 080	4 014
Differences	938	1 617	2 555

Important results have followed from these great improvements. The principal lines now constitute, in their entirety, a homogeneous system upon which the same boat can go from one extremity to the other without breaking cargo, whatever may be the nature of the route over which it passes, the altitude which it reaches in passing from one basin to another, or the climatic conditions of the regions.

Undoubtedly ice, river floods, and inclement weather will never permit of attaining the same regularity as upon railroads. Nevertheless we approach it as closely as possible; we give to the navigable water-way a uniformity which was lacking to it, thus facilitating transportation by water to great distances, and allowing the system to develop under the most favorable and economical conditions.

Streams and Rivers.

The Seine, from Paris to Rouen.—Upon most of the canalized rivers it has been possible to raise existing dams, often, indeed, to replace them by other structures. Those of the Seine, between Paris and Rouen, should be placed in the first rank of such works.

In view of the exceptional importance of this route a depth of 2 m. has not been considered sufficient; and it has been extended to 3.20 m., in order to assure the passage of boats loaded to a draft of 3 m. This work is now completed; the expense, including that of the Paris slack-water level, has reached 61 000 000 francs.

The natural fall of 25.50 m. in the Seine, between the locks of Port-à-l'Anglais, above Paris, and the lowest level of the open sea, below the lock of Martot, near Rouen, a distance of 225 km., has been over-

come by nine dams with locks. There are at least two locks at each dam; the large one has a width at the entrance and exit of 11.80 m., with an available length of at least 151.80 m.; and is designed especially for convoys, which it can receive unbroken, with their towboats; the second, of smaller dimensions, is designed for single boats. The Seine, between Paris and the sea, thus allows the passage of special seagoing vessels having the smokestacks and masts so arranged that they can be lowered for passing under bridges. It is, moreover, frequented by river barges having a net tonnage as high as 1 000 tons, independently of shallops of 300 tons which navigate it in full security.

The locks of Bougival, which serve a double traffic, that from Paris to Rouen by the Seine and to Belgium by the Oise, pass more than 3 000 000 tons per year. They are provided with hydraulic apparatus, which is operated by the fall at the dam of Marly, and by the aid of which all the movements are made by hydraulic pressure.

The dams contain one or more navigable passages, and higher passages or weirs; their modes of construction and closing vary with the locality. Three of them are old trestle and needle dams; the other six can be assigned to two principal types, that of Suresnes and that of Poses.

The dam of Suresnes, built by M. Boulé, Inspector-General, immediately below Paris, at the head of the islands of Puteaux and of La Folie, is composed of three distinct passages, having a total length of 197 m. The normal fall is 3.27 m. What characterizes this dam is the employment of trestles copied from the Poirée system, but extended to a height which had never been attained in that system; their total height varies from 4.14 to 6 m. They are operated by a chain moved by means of a fixed winch placed upon the abutment. Two methods have been adopted for closing which are used alternately, the sliding gates of M. Boulé and the curtains of M. Caméré.

The Boulé gates are made of planks; these rest vertically one above the other, and are supported laterally on two adjoining trestles. The Caméré curtains are composed of a series of horizontal timbers joined by articulations which form hinges. They are supported by two adjacent trestles and, by means of a chain, are held and rolled up like an awning when one wishes to let the water take its natural course.

Gates, or curtains, replace the needles of the primitive Poirée sys-

tem; the operation is by means of a windlass which rolls along the service bridge. They thus obtain solidity, freedom from leakage and facility of operation, while the height of water in the Paris slack-water level can be regulated with great precision. This great dam has worked for several years with perfect regularity, and the expense has been about 10 370 francs per running meter.

At Poses the fall exceeds that of Suresnes; it is 4.14 m., which is greater than had been overcome by means of a movable dam. It is dangerous to depend upon parts constantly submerged to so great a depth. The work was designed by M. Caméré, Engineer-in-Chief, on a new system, which was originated by the late M. Tavernier for the Rhône; but the first application of it was made upon the Seine.

The dam of Poses has a total length of 235 m., divided into seven parts of greater or less depth, each having a length of 30 m. The piers which separate them support a fixed bridge placed at a height sufficient, when the dam is open, for the free passage of the largest floods, as well as the boats.

At the lower part of this bridge, on the down-stream side, long wrought-iron beams are hinged, which hang down to the sill and rest against a projection on it. These beams thus supported at both ends replace the trestles and receive the articulated curtains which close the passage. For the free passage of water the curtains are rolled up; then the beams under the bridge are raised by means of a windlass, and the river is absolutely free, while the working parts fixed to the service bridge above, which is more than 4 m. above the highest water, can be easily maintained and repaired.

Like the preceding, this dam has been in service for several years. The cost, including the foundations, which had to be carried to a great depth by the use of compressed air, reached 16 515 francs per linear meter.

These two fine works, all the details of which were studied with scrupulous care, already serve as models for foreigners; they mark a new era in the canalization of rivers, and maintain the rank assigned to our engineers in this essentially French work of the construction of movable dams.

The Saône.—The Saône and the Rhône constitute together one of our great fluvial arteries. The Saône is entirely canalized for a length of 374 km. In the upper part of its course it is connected by the Canal of

the East with the system of navigable ways in the north and east of France. Fixed and movable dams on the Poirée system assure it a depth of 2.20 m. The locks above Gray have the normal dimensions fixed by the law of 1879, and from Gray to Verdun-sur-Saône, slightly larger dimensions.

In the lower part, below Verdun, the system is different; navigation is carried on by large convoys, and the locks, 160 m. long by 16 m. wide, allow of taking in a complete tow. The dams, six in number, including that of La Mulatière at Lyons, are formed of a navigable pass with Chanoine wickets, and of a weir with Poirée trestles. The minimum depth is 2 m., but the effective depth is generally greater.

Although finished since 1878, the works of the Saône were for the greater part constructed before that date. Among those of most recent execution there may be noted the dam of La Mulatière, built at Lyons by M. Pasqueau, Engineer-in-Chief, at the confluence of the Rhône and the Saône, on a system slightly different from that of the Chanoine dam. It is located at a pass which is, at the same time, broad and deep, where the use of the trip-bar was hardly practicable, and where special difficulties occurred from the nearness of the Rhône. M. Pasqueau has done away with this delicate part, and assured the manœuvre by means of a heurter, or supporting-block, with two notches.

To lower the dam in this new system it is only necessary to draw the breech chain until the prop comes to the second notch. The vertical plane oblique to the axis, which is formed by the lateral face of this notch, causes the prop to fall into the groove, and the wicket, held by its chain, comes gently to rest upon the platform. This modification secures, besides the suppression of a part sometimes difficult to control, the possibility of closing passages of a great width by Chanoine wickets, without which the opening would be limited by the length of the trip-bar. It is thus that the passage of La Mulatière, 103.6 m., could be closed.

This valuable advantage, joined to the facility of working of the Chanoine wickets, has induced Colonel Merrill, of the U. S. Engineers, to adopt this system in preference to all others upon the Ohio, where its use has been greatly extended in recent years. The scale is considerably enlarged, having regard to the dimensions of the American river; but the system is that of the Chanoine-Pasqueau dam, the first application of which was made at La Mulatière.

The Rhône.—The Rhône, whose excessive slope rendered its canalization difficult if not impracticable, offers the single example in France of the unobstructed improvement of a large river above its maritime portion. The regularization has been obtained by M. Jacquet, Inspector-General, and M. Girardon, Engineer-in-Chief, by means of longitudinal dykes of rip-rap, of spurs connecting them with the banks, and of dykes completely submerged, which, crossing the river in the deep places, correct the irregularities of the bottom and fix the depth of the channel. The cost has exceeded 40 000 000 francs. These works, without a single dam upon the Rhône, have been the means of giving a draft of 1.60 m. during 345 days of the year, on 290 of which a draft of 2.00 m. was available, of increasing the capacity of the boats by 24%, and have also enabled them to navigate with greater ease and without other means of traction than their own engines.

Navigable Canals.

Reconstruction of Locks; Elevator of Fontinettes.—Upon the canals the carrying out of the programme of 1879 has involved the reconstruction or enlargement of a considerable number of locks. The difficulty of carrying out this operation with the flights of locks on certain canals, and the opportunity thus presented of eliminating them, wholly or in part, have conspired to the construction of works designed to overcome greater lifts than in the past.

One of the most important of these works is the elevator of Fontinettes upon the canal of Neuffossé. Proposed at first by M. Bertin, Inspector-General, it was subsequently studied and executed by M. Gruson, Engineer-in-Chief. The elevator replaces five locks, which overcame an elevation of 13.13 m. It was copied from that already in use in England at Anderton, for small boats with loads of not over 80 to 100 tons, while that of Fontinettes receives boats of 300 tons. Reduced to its essential parts, it is composed of two caissons or metallic troughs, filled with water, in which the boats float. Each trough is fixed upon the top of a single piston, which works in the cylinder of a hydraulic press, installed at the center of a shaft. The two presses communicate by means of a conduit furnished with a valve in order to isolate them at will. At the bottom and top of their course the troughs can be connected with the lower level or the upper level of the canal as the case may be. Large gates, with

which the troughs and the levels are supplied at their extremities, permit of establishing or intercepting this communication. Three square towers built of masonry carry guides which direct the moving troughs in their course.

The machinery comprises two turbines run by water from the upper level ; one of them serves to charge an accumulator of 1 200 liters capacity ; the other drives an air compressor. The hydraulic presses, which constitute the most important part of this system, are 15.68 m. high and 2.08 m. interior diameter. They are composed of steel rings superposed each 0.155 m. high and 0.06 m. thick ; a continuous lining of copper 3 mm. thick insures tightness.

The elevator was put in service in April, 1888. The time required to pass two boats, the one ascending, the other descending, is, on an average, 26 minutes. The total weight to be raised reaches almost 800 tons. The cost has reached 1 870 000 francs.

In the same line several French engineers, notably MM. Peslin and Flamant, have studied projects with inclined planes designed for boats of 300 tons. These projects present ingenious arrangements, but none of them have yet been put in execution.

Locks of High Lift; Canal of the Center.—In the different applications of mechanics to the elevation of boats by the vertical elevators, or inclined planes, the art of construction has reached, if, indeed, it has not passed, the prudent limits of the resistance of materials. Struck with this danger, other engineers have sought to resolve the same problem in a simpler and more practical manner by the employment of locks with high lifts. This solution is the one which has been adopted upon the Canal of the Center. The new locks of this canal have a lift of 5.20 m.; they have been justified by the same wants and have responded to the same necessities; they replace locks of less than half the lift, of which the surroundings did not permit the lengthening, and where it has been desirable to reduce the number in order to facilitate navigation.

The filling and emptying is controlled by means of cylindrical gates, the fixed part of which is built into the masonry of the side walls, and the moving part, operated by a vertical rod, is entirely supported by the fixed cover. The movable part receives only pressures which are in equilibrium, and consequently is operated with the same facility whatever may be the height of the lift. Water intro-

duced for filling by the head valves is distributed by lateral passages throughout the whole extent of the chamber, to which the depth of 2.60 m. has been given for a normal draft of 2 m. In emptying, the movement is reversed by the tail valves. By this method, the filling or emptying is done in 3 minutes and 15 seconds. The velocity of ascent or descent of boats in the chamber is 1.62 m. per minute ; it is accomplished with very little agitation and without the least danger to the boat. The gates are closed by two abutting leaves protected by iron and galvanized steel. The cost per lock was 120 000 francs.

This elegant solution is due to M. Fontaine, Engineer-in-Chief and his skillful co-laborers. There is no doubt that it is susceptible of numerous applications; one application has been realized quite recently upon the Canal St. Denis.

New Locks of the Canal St. Denis.—This canal, which connects the port of Villette, the most important of Paris, with the Seine, has just been completely transformed. At the same time its depth was increased, like that of the Seine, to 3.20 m., and all the locks have been rebuilt. The new locks contain two chambers, the one of regulation type for canal-boats, the other of larger size for those of the Seine. They are provided with cylindrical valves of the same system as those upon the Canal of the Center. The gates are composed of a single leaf, a metallic body, with a wooden edge, turning around a vertical axis. They are operated by a little turbine run by the fall of the locks. When they are open, they drop back into a recess in the wall which separates the two chambers. This wall contains the passages for filling and emptying the chambers, the turbine, the water pipes, and all the apparatus for working; all the equipment is concentrated here, and the outside walls remain free for circulation.

As upon the Canal of the Center, advantage has been taken of the reconstruction of the locks, to diminish their number, by augmenting their lift. But they have gone farther in this direction and have given to one of them a lift of 10 m. This exceptional lift required some special precautions. In the ordinary system, the tail gates would have attained an excessive height, which would have rendered their construction difficult and their movement very laborious. In order to reduce this height, a masonry shield was constructed at the lower end of the lock which unites the two side walls, for the support (when closed) of the upper edge of the gate, which is of a single piece. Below this

shield there is reserved the necessary height for the passage of boats, and it has thus been possible to bring the dimensions of the gate to those which have been established by practice. As to the head gate, its height was determined by that of the lock wall.

This large lock is also provided with cylindrical valves for filling and emptying the chamber, and with a turbine for working the gates. There is, too, an equalizing basin designed to economize the water used in lockage. Put in service in 1892, it works with all the regularity desirable.

This remarkable work was designed and executed by M. Humblot, Inspector-General and M. Renaud, Engineer.

These examples demonstrate the possibility of overcoming by locks lifts which were formerly regarded as impossible. This simple economical solution, exempt from dangers, permits the difficulties which flights of locks bring to navigation to be overcome without recourse to mechanical appliances, and constitutes the most recent and important progress which has been realized by French engineers in the construction of canals.

Increase in Depth.—The programme of 1878 had more in view than the unification of the type of locks. According to the law of August 5th, 1879, the depth which, in most of the old canals, was only 1.60 m., and sometimes less, was to be increased to 2 m., in all those which were classed as principal lines of navigation. In fact, they have generally been given a depth of 2.20 m., in order to obtain an effective depth of 2 m., in spite of the deposits which may form in the levels, or the inevitable variations of the water level. This second operation has not been less laborious than the preceding, for it required the general raising of the banks, that of all the structures, and the elevation of most of the bridges.

Aqueduct of Briare.—Among the new works designed to procure this depth, the most important is the aqueduct of Briare over the Loire.

At present the canals which constitute the great line of navigation from Paris to Lyons, by way of Bourbonnais, are separated by the Loire, the crossing of which is made at the level of the river. In spite of the channels and improvements constructed a long time ago, during most of the year this crossing offers a totally insufficient depth; moreover, it is not free from danger when there are floods in the river, and it cannot then be considered as a line of the first order.

It has, therefore, been decided to construct an aqueduct 2.20 m. in depth, placed above the highest floods of the Loire, and connected on the opposite banks of the river with the existing canals by branches, which make the total length of the junction level 19 km. This bridge, 600 m. long, consists of 15 spans of 40 m. each. The trunk is entirely metallic; it is supported by two straight continuous girders, 7.25 m. apart in the clear, connected by cross-bracing; the tow-paths are supported by outside brackets. The whole work is designed to be built of steel; it is now in process of construction, and will probably be finished next year. The cost is estimated at 3 000 000 francs, and it will be increased by the approaches to more than 7 000 000 francs. It will be one of the most important aqueducts, and at the same time the largest application of steel to this kind of construction.

Water Supply.—These different improvements, the general increase in depth, the necessity of securing regularity of transportation during the dry season, and the development of traffic have required a very notable increase in the water supply upon most of the canals. In order to attain this end, various methods have been adopted. When circumstances permitted, the increased supply has been obtained by the construction of new reservoirs.

Among such works, that of Torcy-Neuf, designed for the Canal of the Center, merits particular mention. Its area is 166 hectares; the maximum height of the bank is 14.50 m., and the capacity 9 000 000 cu. m. The dam is formed of sandy clay, thoroughly compressed by a 500 km. steam-roller, and faced on the water side by masonry arranged in the form of steps. This reservoir presents a new and characteristic arrangement in its intake tower, which is built inside the reservoir at the foot of the dam. The interior of the tower forms a vertical shaft into which the intake valves, three in number, open 4.80 m. above one another. This shaft also receives the overflow at the top, and opens at the bottom into a waste conduit, which passes through the dam. The tower is reached by a little metallic footbridge.

This arrangement avoids the danger of infiltration, and the expense of a waste-weir over the top of the earth dam; the dam is pierced only at the bottom by the waste conduit, and all the rest forms a stable and homogeneous mass, in which no masonry is interposed.

The cost of this work was about 2 233 000 francs.

In cases where the permeability of the soil or local circumstances

prevent the construction of a reservoir, water has been supplied by powerful pumps from a neighboring river, lifting it to the canal. Several large plants of this kind for newly constructed canals have already been mentioned. The most important of these, the two groups of machines of Toul and of Vacon, contribute both to the supply of the Canal of the East, recently built, and to that of an older water-way, the canal from the Marne to the Rhine, the supply of which had become insufficient. It has incurred a total expense of 2 884 000 francs.

In the absence of reservoirs, such machines offer a valuable means of supplying the deficit. For the same object it is often desirable where it can be done, to reduce the leakage of canals. The method habitually employed in doing this consists in the use of a concrete revetment from 15 to 20 cm. thick, with which the bottom and sides of the channel are covered. Small openings furnished with valves permit an exterior pressure in opposition to the pressure of the water in the canal when necessary. This mode of tightening, due to M. Malézieux, Inspector-General, is already old and established by long practice. But it has received new and numerous applications in the last few years, notably upon the canal from the Marne to the Rhine, and the other canals of the region of the east.

It is by these various methods that we have become able to fulfill the new requirements of water supply. The improvement of the supply has required long and careful researches and difficult constructions, and it is not exceeded, either in cost or in results obtained, by the other improvements of which it constitutes the necessary complement.

Chapter 3.—Traction.

In France, the mode of traction most used is towage by horses; this is the consequence of the predominance of canals in the network of navigable ways in this country. While continuing the employment of horses, the system upon the most traveled canals of the north, and upon the great line of navigation from Belgium to Paris, has been improved by the organization of regular relays established by the State itself by virtue of a decree of June 19th, 1875.

Each of these routes is divided into sections of 12 to 18 km., and the operation of each section is let for six years to a contractor by bidding. The towage thus organized is obligatory on all loaded boats,

as well on the ascent as on the descent, with the exception of boats propelled or towed by steam. The contractors for towage thus enjoy a veritable monopoly. On the other hand, they are required to tow the boats without any delay, with a velocity of 2 km. per hour. They are also required to add at the entrance and exit of locks, enough horses to hasten this double operation as much as possible.

The rates of towage are fixed per ton and per kilometer, according to the rates determined by the bidding. These prices apply both to canals and to canalized rivers, and include, at the same time, a tax for the possible tonnage of the hull and a tax proportional to the actual loading. They are, both together, from 0.0024 franc to 0.0036 franc per kilometer-ton on the descent, and from 0.0031 franc to 0.0058 franc on the ascent.

This organization allows the regular service of a traffic, which, on certain sections of the canals, reaches 3 500 000 tons per year. The constraint which it presents to liberty of towage is caused by the necessity of avoiding any retardation upon much-frequented water-ways, and of preventing encumbrances prejudicial to the common interest. The results obtained fully justify this measure.

For a long time, numerous investigations have been made, in order to substitute mechanical traction applied upon one of the banks for traction by horses. But the system of funicular towage, recently proposed by M. Maurice Lévy, is the only one which has resulted in anything practical. Briefly, in its essential parts, this system consists in the use of an endless cable moved by a fixed motor. The two portions of the cable run, one along the right, the other along the left, of the water-way upon pulleys carried by supports fixed outside the tow-path. The boats are attached singly to the one or the other of these portions according to the direction of the journey; the cable consequently tows up stream and down stream simultaneously.

This system, though very simple in theory, presents in practice serious difficulties, which have been happily overcome by M. Maurice Lévy. The cable is of metal and has been intentionally made very heavy; it weighs 3.65 kg. per linear meter. It is mounted with a tension of 5 tons for each portion, which brings the load upon the tightener to 10 tons and a permanent tension upon the steel strands of the cable of 5 kg. per square millimeter. This strong tension maintains the oscillations of the cable both horizontally and vertically,

within small limits. External forces, oblique traction, and the irregularity of the pull of the tow rope may be taken as quantities which may be neglected.

The supports are placed at intervals of 70 to 80 m.; pulleys of proper form and inclination guide the cable as well on curves as on straight lines; the grooves in the rims of the pulleys prevent the tow rope from disengaging from the cable as it passes over them. Certain ingenious arrangements give complete facility to boats to attach or detach at will without interrupting the motion of the system, and at the same time leave the cable free to rotate upon its axis, which is one of the results of its motion and which constitutes one of the principal difficulties which inventors have labored to overcome.

The most convenient velocity is from 2 500 m. to 2 800 m. per hour. But it offers a regularity and a constancy of motion which cannot be attained with living motors; on account of this circumstance, the time of passage can be reduced one-half.

This system of funicular towage has been installed and kept in service for two years on trial on the canals St. Maur and St. Maurice, near Paris. Following the results of this trial, the administration is prepared to make a first important application in the tunnel of Mont-de-Billy, upon the canal from the Aisne to the Marne.

As to the cost of traction, it depends on the traffic of the canal, since in this system the costs of installation and of operation are almost the same whatever may be the traffic. It is admitted that they will vary from 0.0044 franc per kilometer-ton, for a traffic of 1 000 000 tons, to 0.0016 franc for 3 000 000 tons, per year.

The passing through a canal tunnel, which presents a contracted passage of great length, always constitutes an obstacle to traction. For a long time towage by submerged chain, which permits a convoy of boats to pass through, has been in use. But the velocity is small on account of the resistance which the water offers to the passage of the convoy; the ventilation is insufficient, and it becomes necessary to take special precautions to avoid the emission of smoke. On this account, M. Holtz, Engineer-in-Chief, has used in the tunnel of Mauvages, 5 km. long, on the canal from the Marne to the Rhine, engines of the Francq system, working without fire by means of steam reservoirs placed on the towboat. Outside the tunnel, steam is forced into these reservoirs at a high pressure and is used, during the journey

through the tunnel, in operating the steam motor. This system, which has been in service about 10 years, has given good results.

More recently, M. Galliot, Engineer, has proposed an elegant solution, founded on the use of electricity, for passing through the tunnel of Pouilly, upon the Burgundy canal. His project for electric towing has received the approbation of the administration, and should soon be put in operation. It is as follows: The water supply of the canal, received in the summit level where the tunnel occurs, will operate a turbine at each of the locks at the ends of the level; one of them will be of 21 H. P., the other of 14 H. P. Each turbine will run a dynamo which will each give a current of 16 ampères; the tensions will be 552 volts for one, and 368 volts for the other. These dynamos will be coupled for tension.

The motor will be placed on a small towboat of 12 tons displacement and will receive 16 ampères with a tension of 835 volts.

The line will consist of three conductors of silicon-bronze wire, 7.2 mm. in diameter. The current will be taken by means of jointed supports rising from the boat and making contact by a trolley upon the wire.

Finally, the towboat motor will turn by means of a double gearing the sprocket wheels, which will be mounted in such a manner as to utilize the towing chain. These arrangements will be completed by accumulators, which will be placed on board the boat, to correct the irregularities which may occur from variations in the number of boats to be towed.

Upon the rivers mechanical traction by means of towboats, tugs, or steamboats is generally substituted for towing by horses. These methods have been known for a long time ; the most recent innovation consists in the utilization of electricity, but in a very different manner from the preceding.

We know that in towing by a submerged chain, as it is ordinarily practiced, it is necessary to take several turns of the chain about the winding drums of the towboat, the number being sufficiently large (four or five half turns on each drum), so that the adhesion shall be equal to the necessary force of traction. This requirement presents numerous inconveniences, and produces a rigidity of connection between the towboat and the chain which does not permit of freeing one from the other easily. Now, experience has proved that if the tow-

boat has a superiority over tugs on the ascent, these latter have the advantage on the descent, and the towboat usually descends empty.

The Director of Towing on the lower Seine and the Oise, M. de Bovet, has sought to avoid this rigidity by the use of a magnetic pulley, which he has substituted for the winding-drums. In this system, the chain passes only once over the groove of the pulley; adhesion is obtained by an electric current, which magnetizes the groove and which can be turned on or off at will. It thus becomes easy to disengage the towboat from its chain. The boat, constructed like a tug, is supplied with a towing apparatus which it uses only on the ascent. It can leave the chain at any point of its course, and descend as a tug.

After investigating for several years, M. de Bovet seems to have solved in a practical manner the numerous difficulties of detail which this problem presents ; the new towboat tug, constructed on this system, will be put in regular service on the Seine and Oise in the course of the year 1893.

We see that on all sides, engineers and constructors are seeking to improve the means of traction, and that important progress has been realized in the last few years. In the same general direction, several engineers have made theoretical and experimental studies of the greatest interest. There may be noted, among others, those of M. de Mas, Engineer-in-Chief, and those of MM. Caméré and Clerc.

The first is especially interested in determining the different elements which enter into the resistance of a boat to traction ; given the immersion, the form of the immersed section, and the nature of the surfaces in contact with the water, to be able to separate the influence of each of these elements in the total traction. The other two have had more particularly in view experimental researches into the tractive force in the different levels of a canalized river, so as to find out the easiest passages, and those, on the contrary, where, on account of a contraction of the bed of the river, or for some other cause, the power required is very great.

In conclusion, all the efforts converge not only toward the improvement of the navigable water-ways, but also toward their better utilization by perfecting the methods of traction.

Section III.—Expenses and Traffic.

Chapter 1.—Expenses; General Considerations.

After having thus described the principal betterments carried out upon our network of water-ways since 1876, and before seeking to show the results obtained, that is to say, the influence exercised by the completed work upon the development of the circulation and the new facilities of every nature which they have assured, it is believed it will be useful to indicate what the cost of these works has been.

From 1876 to 1891, the amount expended under the title of "Works for the Establishment and Improvement of Navigable Water-Ways," was, altogether, 564 000 000 francs. But this round number, applicable to the whole network, includes operations which, although really carried on upon navigable rivers and canals, cannot be considered as pertaining solely to the improvement of navigation. These figures present some discrepancies, especially if one wishes to bring together those which measure the increase in traffic due entirely to the new works.

	Francs.
Let us consider first that portion of the expenses pertaining to the navigable water-ways in the south, southwest and west, and a portion of the center ; water-ways which ought not to be included, or which have not been included, in the work of unification. The greater portion of the expenses which concern them have been on works executed in the maritime portions of the Loire, the Garonne and the Charente, which pertain exclusively to maritime navigation and, consequently, ought not to be charged to interior navigation. The sum to be deducted under this head amounts to.....	83 000 000
It is likewise reasonable to deduct a portion of the expenses made for the betterment of the maritime portion of the Seine which, properly speaking, constitutes the channel of access to the port of Rouen, and where the depth, even before these improvements had been commenced, was sufficient for the inland boats. Under this head there should be deducted an expense of...	14 000 000

	Francs.
Brought forward.....	97 000 000
We should make a separate account for the waterways in the course of construction or improvement, and which have been, consequently, unable to show the growth in circulation and traffic which the works in course of execution ought to assure to them; these, for canals still in the course of construction, amount to.....	66 000 000
and for the lines in course of improvement only, amount to.....	55 000 000
Altogether, the deductions to be made are.....	218 000 000
If we subtract this sum from the total previously indicated, we find that the actual expenses really pertaining to the parts of the network on which the improvements undertaken under the laws mentioned at the beginning of this memoir are now completed, amounted on January 1st, 1892, to.....	346 000 000

These will be considered for each of the great lines in the chapters which are devoted to them, respectively.

Chapter 2.—Traffic; General Considerations.

In order to establish, year by year, useful comparisons of traffic, concerning the system of routes of communication, the best unit is the kilometer-ton, that is to say, the ton of 1 000 kg. moved 1 km. The "kilometric tonnage" is the sum of the products obtained by multiplying the weight (in tons) of each cargo by the number of kilometers which it travels.

In 1876, the kilometric tonnage of the navigable ways of France was.....	1 953 000 000	kilometric tons.
In 1891 it had increased to...	3 537 000 000	" "
Difference.....	1 584 000 000	" "
Making an increase of.....	81%.	

This increase being for the whole system, it was affected by the unfavorable results on certain parts of the system upon which the

work of unification had not been carried out; on some of them, far from concurring in the general increase, there was a diminution in their special circulation. If we consider the single lines where the boats transport ores, and which already had a depth of 2 m., the results are infinitely more satisfactory. This is shown in the following table:

	Length in kilometers.	Kilometer tonnage (in thousands of kilometer-tons.		Increase.	
		1876.	1891.	Actual.	Per cent.
Seine (from Montereau to Rouen)....	344	289 607	639 864	350 257	121
Line from Belgium (from Conflans to the Belgian frontier).....	299	439 991	731 272	291 281	66
Lines from the Escaut to parts of the North Sea.....	441	174 516	389 356	214 840	123
Line from Paris to the German frontier).....	452	164 078	324 578	160 500	98
Canal of l'Est (from Givet to Corre)..	432	344	197 048	196 704	
Junction of lines from the east and north (canals from the Oise to the Aisne, lateral to the Aisne, Aisne to the Marne.).....	157	45 706	93 157	47 451	104
The Saône (from Corre to Lyons)	374	69 162	102 343	33 181	48
Totals.....	2 499	1 183 404	2 477 618	1 294 214	109

Thus, upon these different portions of the system, the only ones which are of interest in this study, the increase from 1876 was 109 per cent. It should be remembered, however, that upon many portions of the lines given in the preceding table, the completion of the work is of very recent date, and that the improvements realized are far from having yet produced their entire effect upon the development of traffic. There is no doubt that after the completion of the works of unification of the lines from Paris to Lyons by Bourbonnais and Burgundy, there will be shown, not only upon these lines, but upon all the routes which are in communication with them, a development of traffic no less remarkable, and no less rapid.

The increase of the kilometer tonnage gives only one side of the aspect of the circulation. Previously to the period which has been considered, the diversity of the depths, and that of the dimensions of the structures, formed serious obstacles to long trips. The waterways were most often utilized for local and restricted circulation only.

The object of the unification of the system was to permit transportation to long distances without lightening or trans-shipment. It is, in fact, only for long journeys and important cargoes that navigation produces its maximum efficiency. The annual cost of a boat capable of carrying several hundred tons of freight is not much greater than that of a boat of small dimensions. The cost *en route*, aside from traction, especially for boats which do not carry their own propellers, is, so to speak, insignificant. The really important expenses are those which attach to each special operation of transportation at departure and arrival; loading, unloading, supervision, storage, etc., which in English are designated by the name of "terminal charges." Now, if the expenses for material and labor are distributed over all the operations of transportation effected in the year, the terminal charges will be distributed over the units of traffic to which these charges belong, that is to say, over the total kilometer-tons which make up the operation. Though very heavy, if confined to a journey of a few kilometers, the cost becomes much less if it is to be distributed over the hundreds of kilometers of an extended trip.

In fact, for distances of a few kilometers, and at least for places of production and consumption, situated upon the banks of the same water-way, navigation cannot even compete with carting. The same causes of inferiority are found for trips of average length, with regard to competition by railways, which, by reason of their flexibility in alignment, present a real superiority over water-ways, and adapt themselves more easily to branch lines for industrial growth.

On account of these different considerations, and in order to appreciate the results of the work for the unification of the navigation system, it is very important to show the increase of the average journey effected upon the system. The comparison unfortunately cannot be established with that of the year 1876, adopted as the starting point for this study. At that time the annual statistics did not give separately the effective weights of cargoes, but the movements by separate routes only. We would have thus for each river or canal the number of tons which were moved over it, but those elements of traffic which pass successively over several water-ways, in order to complete their journey, cannot be summed up without adding them more than once. It is only since 1881 that the traffic accounts have been kept, not only by routes, but also by the separate cargoes shipped.

In 1881 the total weight of cargoes shipped reached	19 740 000	tons.
In 1891, the same total reached.....	24 167 000	"
The actual increment was	4 427 000	"
The percentage of increase is	22	per cent.
On the other hand, the total kilometric tonnage reached in 1881 ..	2 174 000 000	tons.
It reached in 1891.....	3 536 000 000	"
The actual increment was	1 362 000 000	"
The percentage increase was.....	62	per cent.

The increment was thus 22% on the effective tonnage (weight of cargoes), and 62% on the kilometer-tonnage.

The progress realized was then mainly in the length of trips; or, in other words, what the new cargoes gained by the navigable way correspond to the lengthening of the haul, profiting, consequently, by the economy which interior navigation secures by long journeys.

A very simple calculation will make clear the progress realized in this direction. The increment of 4 427 000 tons of cargo corresponds to an increase of 1 362 000 000 km.-tons. If we admit that the old streams themselves have not been modified, the average length of the new journey would be 307 km., while the average journey in 1881, 10 years previously, was only 110 km. This result demonstrates the efficiency of the works already completed.

If we recall the facts that the completion of the works of unification is, for the greater part of the improved water-ways, of a very recent date, and that especially the works undertaken on the lines of the center are not yet finished, and have as yet been able to exercise no influence upon the circulation, we may predict for the near future a new and considerable lengthening of the average journey, and important progress of navigable water-ways in the line of the service which they are best able to render.

The unification of the depths and of the dimensions of the navigation works could be made efficacious only by bringing about a corresponding change in the *materiel* or the fleet, and of its means of traction—boats and motors.

The interior navigation fleet in France is composed of the most incongruous elements, and a calculation of averages based upon capa-

cities and forms and also upon methods of use which are not correlated would not be of interest. Some general indications in this respect, however, will not be amiss. A general enumeration of the fleet in France was made for the first time in 1887, and revised in 1891. The comparison of the results at these two dates, which, however, are only separated by a space of four years, nevertheless furnishes valuable indications, and shows with what enthusiasm the business of transportation has hastened to profit by the new facilities given to the circulation of boats of larger dimensions and of more perfect forms, and to the employment of more economical motors.

The total of freight boats enumerated was:

In 1887.....	15 730	boats of net tonnage...	2 713 847
In 1891.....	15 925	" " ...	2 996 230
An increase in favor of 1891 of.....	195	" " ...	282 383

The increase in net tonnage was about 10 per cent. But if one extends the comparison to the types of boats in use when the dimensions of the programme of unification were adopted, we arrive at much more favorable results. The number of boats 38.50 m. long and more was:

In 1887.....	933	boats with total net tonnage of...	342 933
In 1891.....	2 016	" " " ...	747 758
Increase.....	1 083	" " " ...	404 825

The increase of boats of the new type amounts to 54 %, whether one considers the number or the capacity. The force employed on the fleet received, in the same time, an increment corresponding to the increase of the *materiel* and the activity of transportation (6% in four years). The greater part of the *materiel* of the fleet is composed of flat boats, generally of wood, and put in motion by an outside motor.

Steamboats do not accommodate themselves well to canal navigation. Short levels and flights of locks slacken the speed, and do not permit the steam motor to be used sufficiently to render it economical. It is the same as regards steam towing. Thus, steamboats and towboats are concentrated upon rivers and streams—there only where the circulation is free, and where they meet levels of sufficient length (Seine, Rhône, Saône).

In order to give an idea of the results obtained by the transformation of the system of interior navigation, it is not sufficient to present the increments of circulation. Progress, in the matter of the means of transportation, results from multiple conditions. There may be cited the economy due to lowering the price of freight, to increasing rapidity, to greater regularity, to the diminution of the risks *en route*, to greater facilities on arrival and departure for loading and unloading, and for transferring freight to the connecting routes which take it to the ports of departure or to its final destination.

These various conditions cannot readily be expressed in statistical form or in a synthetic sketch. We shall, nevertheless, see further on that, especially where unification has permitted new routes to be established and places of production to extend their power of expansion, a progressive reduction in freight rates has occurred.

Chapter 3.—The Seine.

This chapter will deal only with the portion of the Seine comprised between Montereau and Rouen, since below that city it belongs principally to maritime navigation. The chapter will be divided into two sections; the first treating of the portion from Montereau to Paris, the second of that from Paris to Rouen.

Section I. *The Seine from Montereau to Paris.*—As early as 1875, the normal depth of the Seine from Montereau to Paris (98 km.) was 1.60 m. The work of increasing this depth to 2 m. was only finished in 1884. Nevertheless, the commerce since 1876 has been of real importance. Expressed in kilometer-tons, it was more than 80 000 000; in 1884 it was 112 000 000 and in 1891 it was 160 000 000. In seven years it had gained 48 000 000 km.-tons, or about 33 per cent. It has doubled in 17 years.

At the same time, the average rate on freight, which, in 1876, was 0.03 franc per kilometer-ton, was lowered in 1891 to 0.017 franc. These average values are taken from through shipments extending beyond the Upper Seine, and in applying them to a trip made upon the latter, its share, *pro rata*, is used. If it were possible to separate the part belonging to this section of the river for the long trips, we would certainly arrive at a freight rate lower than that which has just been given.

If we consider only the length and the width of locks, the upper

Seine could be frequented by boats of considerable dimensions; barges of 1 000 tons capacity are already in use, but these are only the exceptions. As a nearly general rule, it may be said that the boats which frequent the Upper Seine are *en route* to or from provinces on the affluent lines. Thus, their dimensions, their displacement and, consequently, their net loading, depend much more upon the conditions of navigation upon the affluent water-ways than upon those of the Upper Seine. This is the explanation of the relatively small figures which we find for the average cargo; still, considerable progress has been realized in 15 years. In 1876 the average boat load was: descending, 122 tons; ascending, 78 tons; average of both directions, 111 tons. In 1891 it had attained: descending, 178 tons; ascending, 142 tons; in both directions, 166 tons.

It should not be forgotten that canal-boats of the legal type are capable of taking a net load of 300 tons, and in spite of the fact that the capacity of the boats could have been immediately increased 15 years ago, the average load in 1891 was not much over one-half the maximum load of canal-boats of the legal type. It is, indeed, in the methods of traction that the work of improvement of the Seine has produced a true revolution in permitting the regular use of screw-tugs.

In 1876, as in 1891, nearly all the common modes of traction could be seen on the Upper Seine; towage by submerged chain, by tugs, by horses or by men; a few boats and rafts descended in the current by means of oars, poles and even, rarely, by the wind. In 1876 most of the towage, about 80% of the total, was by submerged chain. In 1891 the proportion of the total tonnage drawn by the chain had decreased to 49%, 35%, and even 27%, according to the portion of the route considered, while the proportion towed by boats had increased to 44%, 55%, and even 71 per cent.

This competition has resulted in a considerable decrease in the cost of traction. In 1876 the current rates for towage per kilometer were established upon the following basis :

	Francs.
Ascent per ton of possible burden per kilometer..	0.0035
Ascent per ton of actual burden per kilometer....	0.015
Descent per ton of possible burden per kilometer.	0.000875
Descent per ton of actual burden per kilometer...	0.00375

Since 1891 these rates have been reduced 20%, and now only consti-

tute maxima susceptible of considerable reductions, according to the condition of the water and the demands of commerce. It is not too much to affirm that the price of traction has gone down more than one-half.

The cost of the works executed under the law of June 13th, 1878, for increasing the depth of the Upper Seine to 2 m., and for various other improvements, has risen to 6 000 000 francs.

The Seine, from Paris to Rouen.—In its present condition, the lower Seine, including the Paris slack-water level, has a length of 250 km., divided into 10 levels. The works have already been considered in this paper, and have been put in service as fast as completed. But it is only since September 15th, 1886, that the route has been open throughout to a depth of 3.20 m. In 1875 the total kilometer-tonnage of this section of the Seine was less than 200 000 000 km. In 1887 it had already reached 290 000 000 km.-tons, and in 1891, 480 000 000 km.-tons. The increase from 1875 is 140%, of which two-thirds apply to the last six years. Towage by horses, which still preserved some importance in 1875, had completely disappeared in 1891. The employment of steam was particularly developed on this part of the Seine. At the time when the enumerations for 1891 were completed, there were upon the Seine, between Paris (above) and Rouen, 32 freight boats, of a total capacity of 8 060 tons and 3 120 horse-power. Four years before there were only 30 freight boats, with a capacity of 6 211 tons and 1 816 horse-power. The tugs enumerated on the same sections were 54, with 7 465 H. P., in place of 48 tugs, with 4 024 H. P., in 1887. There were 14 submerged-chain towboats using 1 365 H. P., in place of 20 boats and 1 577 H. P. in 1887. The submerged chain lost ground. But this loss was compensated by a remarkable increase of freight boats and tugs. An analogous transformation has manifested itself in the *materiel* of ordinary boats (without motors); the dimensions have been increased, and the advance has not yet ceased.

Finally, the results of the transformations carried out in the technical conditions of the navigation of the lower Seine can be summed up as follows: By the construction of new dams of more perfect type, and the remodeling of the old ones, a minimum depth of 3.20 m. corresponding to a draft of 3 m. has been assured at all times between Paris and Rouen, without interruption, while in 1876 the depth frequently decreased in times of low water to less than the nominal 2

m., and sometimes even to less than 1.25 m. Towage from the towpath may be said to have disappeared ; towage by submerged chain has lost its importance; and transportation by tugs and steamboats has very greatly increased : the time of the trip from Rouen to Paris (ascent) has diminished about 20%, while the efficiency of the boats has sensibly increased, and has reached 80% for the ascent and 40% for the descent.

Many owners have been able to make improvements in their boats with a view of utilizing the depth of 3.20 m. Thus, at the present time, certain barges carry from 900 to 1 000 tons of freight, while, in 1876, the tonnage of the largest barges did not exceed 600 tons ; the steamtugs have engines of 500 H. P., instead of 80 and 100 H. P., and seagoing steamers of 450 H. P. ascend as far as Paris with loads of about 500 tons.

Finally the comparison of the price of transportation for 1876 and for 1892 shows, for the entire distance from Paris to Rouen and return (243 km.), a diminution of 2.30 francs on the descent, or 47%, and 2.70 francs on the ascent, or 43%, corresponding to reductions of 0.009465 franc and 0.011111 franc per kilometer, respectively.

It is to be presumed that the price of transportation will experience new reductions from time to time, with the better utilization of the depth of 3.20 m., and of the boats navigating the lower Seine, and that the time is not far off when it will fall to 3 francs per ton on the ascent (0.0123 franc per kilometer-ton) and to 2 francs per ton on the descent (0.0082 franc per kilometer-ton), leaving out the express freights which represent only a small part of the traffic.

Chapter IV.—Principal Line from Paris toward Belgium (from the Confluence of the Seine and the Oise to the Belgian frontier, near Mons).

The length of this line, which includes both canalized rivers and canals, is about 283 km. The different sections offered ordinarily in 1876 a uniform depth of 2 m.; but the widths of the channel, the dimensions of the locks and the heights under the bridges were slow to respond to the conditions of the programme until late in 1879. Since then, the line has not only undergone transformations which conform to the work of unification, but it has received at the same time numerous improvements in detail.

These transformations have been executed by virtue of the laws of July 27th, 1880, and December 10th, 1886. All the improvements contemplated have not yet been realized. Important works, notably the doubling of locks, should be undertaken soon, in order to give passage to a traffic constantly increasing. The following table gives the traffic in 1875, 1885, and 1891, upon the different water-ways of which the line is composed:

	Length.	Kilometric Tonnage.			Per cent. increase since 1875.
		1875.	1885.	1891.	
Canal from Mons to Condé	Kilometers. 5	Tons. 4 200 000	3 449 000	3 341 000	— 24
Escaut	48	70 000 000	69 972 000	79 504 000	+ 13
St. Quentin Canal	93	175 000 000	221 805 000	305 802 000	+ 75
Canal along the Oise	34	65 000 000	81 917 000	83 731 000	+ 37
River Oise	104	140 000 000	195 635 000	247 738 000	+ 76
Totals		454 200 000	582 779 000	725 116 000	+ 60

At certain locks of the line there were passed, in 1891, more than 21 000 boats, having a total tonnage of over 3 500 000 tons. The improvements realized upon the line, and which have permitted this remarkable increase of traffic, have, moreover, rendered the traction of boats easier. At the same time that the speed of the boats has become sensibly more rapid (25 days in place of 32, in the total distance), the frequency of necessary stops and the length of delays of all kinds have been considerably reduced. The boatmen have been able, on this account, to double the number of their annual trips, which has diminished the general cost by one-half. This diminution, added to the economy which they realize in the cost of traction, has permitted them to reduce the freight charges from 15 to 20 per cent. The reduction would doubtless be greater if it were not for a considerable obstruction to the free play of competition upon the line. Besides, we ought, also, to consider in the profit realized by consignors and consignees the increased rapidity and facilities of every kind assured to commerce.

The improvement of this line has cost only 12 000 000 francs up to the present time.

Chapter 5.—System of the North and of Pas-de-Calais.

This system consists of 20 water-ways or sections, rivers and canals, measuring together 523 km. The most important collieries of France are concentrated in the departments of the north and of Pas-de-Calais. The routes which traverse them belong to the general system, and are in communication with Paris by the canal of the Sensée, which connects with the middle Escaut, and becomes thus in a manner an affluent of the line from Belgium toward Paris. The works of unification have been carried out under a series of distinct laws, promulgated from 1875 to 1884.

The kilometric tonnage of this system was 160 000 000 km.-tons in 1875. It has increased to 428 000 000 km.-tons in 1891. The actual increase is 260 000 000 km. tons. The percentage increase is more than 150 per cent. Certain lines share in this increase in such a manner as to merit special notice. These are :

The upper Deule, which touches the city of Lille (57 km.) ; its traffic has risen from 45 000 000 to almost 100 000 000 km.-tons.

The canal of the Sensée, a branch of the great line to Paris, the traffic of which has risen from 20 000 000 to 60 000 000 km.-tons.

The canal of Aire (44 km.), which connects the Deule with the canal from Neuffossé to La Lys ; its traffic has risen from 25 000 000 km.-tons to 75 000 000.

As on the Belgian line, so on the routes of the north and of Pas-de-Calais, we find that the character of the boats has been much improved. Almost all the new boats have been built upon the type of 300 tons. A large number of old boats has been modified so as to conform to this type. Hand-towing, still common in 1875, has almost disappeared. Towage by horses has become the general rule, and the quality of the horses has been much improved. Upon a certain number of exceptional ways the towage has been organized by the administration. to the great profit of the fleet as to velocity and economy. At other points special steam towing with submerged chain has been established, and is very prosperous.

It is certain that all these causes united, as also the pains taken to reduce the necessary and accidental delays, have considerably diminished the losses of time which were so great before. The velocity of travel has been notably increased, and the boatman who in 1875 was hardly able to make three round trips per year between the colliery

basins of the north and Paris can easily make five to-day, provided he is active and provident.

The price of freight has not sensibly diminished upon this line; but as upon the line from Belgium, this is due to a lack of competition and also to the fact that under the old régime the principal water-ways, while inferior to the present ones, nevertheless permitted the circulation of boats having a capacity approaching that of the Flemish canal-boats. Transportation enterprises have more especially profited by the diminution in the cost of returning. But producers and consumers have found it also to their advantage, not only in the considerable increase of the capacity and frequenting of the ways, but also in the economy of time and the greater regularity of transportation.

The expenses devoted to the improvement of this system have reached 32 000 000 francs.

Chapter 6.—Line from Paris to the East.

This line runs from the mouth of the Marne, a little above Paris, to Charenton. It includes a part in the bed of the River Marne, canalized with locks for 179 km. Then 373 km. of canals. The Marne and the canal by its side form the principal portion. The canal from the Marne to the Rhine, which is found at the eastern extremity (210 km.), serves, especially in the neighborhood of Nancy, numerous industrial establishments situated upon its banks, notably blast furnaces, forges and foundries, iron mines, salt works, soda factories and chemical works.

The transformation of the line, where the depth has been increased to 2.20 m. and the locks lengthened to 38.50 m., has been effected by virtue of different decrees from 1878 to 1882. The transformation of the boats has followed closely upon that of the route, which has sensibly increased the power of transportation. It is principally in the last few years that the average tonnage of the boats has been increased.

The diminution of the time of passage, very noticeable on the canalized Marne, appeared of slight importance in the trip through the canal from the Marne to the Rhine. The improvements carried out have doubtless had the effect of preventing delay and of facilitating the passage and increasing the size of boats; but, on the contrary, the considerable increase of traffic upon the canal from the Marne to the Rhine has multiplied the causes of delays and blockades, espe-

cially at the locks, which are very numerous (113), and which, with the tunnels, require at least a third of the normal time of passage of boats. For a great number of trips, going from one part of the region of the east to another, we nevertheless find a real reduction. This reduction must be principally attributed to the opening of new routes. Thus the canalization of the Meuse (northern branch of the Canal of the East) has resulted in reducing to 20 or 22 days the trip from Nancy to the coal mines of Liége and Couillet in Belgium, which formerly occupied 40 days, when it was made by the routes of the north and of the Sambre. Likewise, the construction of the canal from the Oise to the Aisne has brought about a gain of 4 or 5 days in the trip from Nancy to the coal mines of the north of France.

There has been on this line a much more noticeable reduction in the price of freight than that which has taken place upon the lines described in the preceding chapters. From the collieries of the north to Nancy the cost of transportation of coal has fallen from 9.50 to 7.50 francs, and from Nancy to Paris from 9 to 6.50 francs. From Nancy to Lille, for salt and soda, the reduction is much greater, from 9.50 to 5 francs. It is not rare to-day to see the price of freight drop to 0.01, 0.009 and even 0.008, franc per km.-ton for certain kinds, such as pig iron and iron ore, transported as a return load by boats which have brought coal from the north of France or from Belgium to the metallurgical establishments in the basin of Nancy.

In order to bring out the progress realized upon this line, it only remains to give the comparison of the kilometric tonnage at three periods, 1875, 1880 and 1891. It may be remarked that from 1875 to 1880 the tonnage on this line had, without doubt, suffered a considerable depression from railroad competition. The upward movement only shows itself since the completion of the works.

	Kilometric Tonnage.		
	1875.	1880.	1891.
Canal from the Marne to the Rhine	106 000 000	83 000 000	216 000 000
Canal along the Marne	27 000 000	27 000 000	57 000 000
Marne	21 000 000	25 000 000	51 000 000
Total	154 000 000	135 000 000	324 000 000

The decrease in traffic from 1875 to 1880 was 12%; from 1880 to 1891 it was 140 per cent. The cost of the work done on this line is 14 000 000 francs.

Chapter 7.—Canal of the East.

This is a new route, 432 km. long, designed to re-establish in our territory the economy of our system of navigable ways, which was considerably interrupted by the new frontiers imposed upon us by the war of 1870–71. It starts from the Belgian frontier at Givet, and connects with the Saône at Corre. There is nothing here for a comparison with the past. The traffic furnished by this route in 1891 was 198 000 000 km.-tons, a great part of which extends over the remainder of the system and comes in for a large part in the increase of traffic shown by the statistical figures already quoted.

This canal has contributed largely to the reduction of the average price of transportation, by favoring the lengthening of certain trips by water. Thus it makes it possible to bring to Creusot, for example, the castings of Meuthe and Moselle, which could not previously be brought there by rail at a reasonable price. The coals of Belgium and the north, of superior quality, have entirely supplanted Prussian coals in the Vosges; the metamorphic sandstone paving stones of the Vosges are brought to Rouen, Calais and Dunkirk, replacing the original Belgian pavements.

Chapter 8.—Water-Ways Connecting the Canal of the East with the Lines from Paris to Belgium and from Paris to the East.

Three of these water-ways are old:

First.—The canal of Ardennes (88 km.), starting from Pont-à-Bar, upon the northern branch of the Canal of the East, and connecting at Vieux-les-Asfeld with the lateral canal of the Aisne, which latter, following along the river Aisne, connects with the line from Belgium to Paris.

Second.—The lateral canal of the Aisne (51 km.), followed by the canalized Aisne (59 km.), as mentioned above.

Third.—The canal from the Aisne to the Marne (58 km.), which connects the two preceding canals with the line from Paris to the East.

A fourth water-way constructed anew and opened only in 1890, the canal from the Oise to the Aisne (48 km.), has for its object the improvement of the connection by water between the north and the east of

France by procuring, with reference to the old distance, a reduction of 56 km., and in avoiding 61 km. of river navigation.

The work of improving the structures on the three old canals is nearly finished, and it has already brought manifest fruits. The boats of the northern lines, shallops and barges, ply there, and the average load has been increased 40 to 47%, with a corresponding reduction in the price of freight.

The velocity of boats on the open levels varies little, but the reduction of the time of lockage and the improvement of certain difficult passages have brought about a general diminution of the length of trips, so that the trip from Pont-à-Bar to Paris (369 km.) is made today in 12 days, in place of 15.

The traffic of the canal of the Ardennes has increased in a remarkable manner, notably since 1885. Like that of a part of the canal along the Aisne, this increase began in large part with the opening of the Canal of the East, and with that of the canal from the Oise to the Aisne. The opening of this last canal has brought about, moreover, a considerable shifting of traffic, as is shown by the following table for this and the other canals.

	1875.	1885.	1890.	1891.
Canal of the Ardennes	9 500 000	12 256 000	17 941 000	22 978 000
Canal along the Aisne	20 796 000	25 390 000	27 207 000	31 532 000
Canalized Aisne	36 856 000	40 203 000	23 818 000	9 149 000
Canal from the Oise to the Aisne	36 856 000	40 203 000	24 741 000	55 939 000
Total	67 152 000	77 849 000	93 507 000	119 598 000

If we consider the shortening produced by opening the canal from the Oise to the Aisne, the traffic of which has developed at the expense of that of the canalized Aisne and a part of the canal beside the Aisne, we shall see the remarkable increase of circulation upon these different lines. This increase is 142% for the canal of the Ardennes, which is the only one properly comparable.

The canal from the Aisne to the Marne (58 km.), which connects the preceding group of water-ways with the line from Paris to the East, has, like them, been improved.

Its traffic, throughout the whole course, changing with that of the routes which it connects, has risen from 27 261 000 km.-tons in 1875

to 32 416 000 in 1891. The proportional increase is 19 per cent. The conditions of velocity and of price have not materially varied on this canal.

The expenses contracted on the lines connecting the routes of the north and of the east have amounted to about 40 000 000 francs, of which 33 600 000 francs were for the construction of the canal from the Oise to the Aisne.

Chapter 9.—The Saône from Corre to Lyons.

The navigable Saône comprises three distinct sections: 1st, from Corre (junction of the Canal of the East) to St. Jean-de-Losne (mouth of the canal of Burgundy), 136 km.; 2d, from St. Jean-de-Losne to Barbe Island (above Lyons), 202 km.; 3d, from Barbe Island to the Rhône (Lyons slack-water level), 9 km.

The works of improvement were completed between 1882 and 1885; and in order to show the importance of the traffic, the kilometric tonnage in 1875, 1885, 1891 is given.

	1875.	1885.	1891.
First Section	5 329 000	22 259 000	30 259 000
Second Section	71 634 000	69 032 000	69 787 000
Third Section			2 296 000

The work of the canalization has reduced the distance by 25 km., which is to the disadvantage of the years 1887 and 1891, in this calculation.

The work of improvement of the Saône has brought important results so far as concerns the development of traffic, only upon the first section which joins the Canal of the East and receives the canal of Burgundy. The proportional increase for this section reaches nearly 500 per cent. It has thus become, so to speak, a new water-way.

Navigation is already established upon the Burgundy canal, where the locks have been lengthened. It is not so with the two lower sections which communicate with the Rhône, where the work of transformation is not yet finished, and with the line from Paris by Bourbonnais, where the completion of the work of unification will doubtless still require two or three years. However that may be, it should be stated that the conditions of navigation of the Saône have been very much improved. The average load of the ordinary boat, which in 1876 was

only 75 tons, had risen to 125 tons in 1891. Steam navigation is developing there. While in 1876 there were only 13 tugs and steamboats, having a total of 764 H. P., the number of these boats is now 24, and their horse-power 1 738. The work of improvement executed since 1876 has cost about 14 000 000 francs.

Chapter 10.—The Rhône from Lyons to St. Louis (327 km.).

Although the Rhône does not figure in the list of water-ways fulfilling the conditions of depth provided by the programme of 1879, the results obtained by means of the work thus far executed have been considerable. At the time when the works upon the Rhône were undertaken, navigation there was rapidly decreasing. Perhaps on no river had boating been so severely tried by the opening of railroads, and its ruin appeared so complete that people had become accustomed to consider navigation as a means of transportation practically condemned and destined to be entirely replaced by railroads.

At the time of the greatest development of navigation, before the victory of the railroads, transports were divided into three types: boats for the transportation of passengers and freight, lightly loaded on the descent, but taking the most important part of the traffic upon the ascent; boats descending with the current, and taking the principal part of the traffic upon the descent; finally, grapnel towboats descending without convoys, and ascending with empty or partially loaded boats, which comprised only a relatively small part of the upstream tonnage, because of the irregularity of their service.

Thus there were in fact two systems, one well adapted to the conditions of ascent, but stopped by low water, and bearing only a small traffic on the descent, the other irregular in its movement and not economical on the ascent on account of the magnitude of the resistances and the stoppage of the tugs by high water. It is evident that this was a cause of weakness which did not permit the boats to give a large return, and that the types least adapted for work in both directions would be less capable of adapting themselves to the new conditions created by the competition of railroads and of overcoming it. This is in fact what has taken place.

Navigation by descending with the current has been most extensively employed; this movement, which in 1884 amounted to 236 000 tons for the total distance between Lyons and Arles, had decreased to

33 000 tons before the law of 1878. It continued to decrease until the first improvements in the river were felt; the minimum was in 1880, and was 24 000 tons. Since then it has increased a little. This mode of navigation has lost its principal freight, coal, not only on account of its own imperfections, but also on account of the absence of all means of exchange between the river and the railroads which connect the Rhône with the colliery basins; it has found it anew, and notably in freightage of lime, and the traffic in this was brought up in 1891 to 38 000 tons.

Navigation by towing by the aid of grapnels in ascending has suffered the same decrease, and for the same reasons. Its traffic, which had reached 67 000 tons at one time, had fallen in 1878 to 5 700 tons. It has risen a little since. A new grapnel towboat, which was designed in view of the new conditions of the river, and which can be used with the highest water, has recently been tried. The movement by steam navigation (tugs) reached 14 000 tons in 1891.

Very different has been the situation of navigation by steamboats. They presented the double advantage of being able to run in both directions with a sufficiently great velocity; they suffered long delays caused by insufficient depth, but should profit immediately as a consequence of the improvements in the river. The traffic by steamboats had reached, before the opening of the railroads in 1887, 242 000 tons of freight between Lyons and Arles, with a considerable number of passengers. The steam fleet comprised 61 boats of a total of 24 000 H. P., among which were 5 grapnel towboats, and 18 boats more especially devoted to the transportation of passengers.

In 1857, immediately after the opening of the line from Lyons to Avignon, the passenger movement decreased considerably, and the freight transported fell to 160 000 tons. Half of the fleet remained at anchor; the traffic continued to decrease from year to year, and they continued to dismantle the boats.

In 1877, the year which preceded the law for improvement, the movement of freight was only 89 000 tons; there were only 10 boats in use, of which 6 were for freight only, 2 for passengers and freight, and 2 tugs. There was a gradual increase from this time; in 1880, it was 115 000 tons; in 1886, 130 000 tons, and in 1891, it had reached 161 000 tons. In 1891, the fleet included 20 steamers in regular service, comprising: 3 small towboats, upon cable, for local service; 4 boats for both freight and passengers, and 11 large boats for freight only.

It may be noted that the movement of freight by boats had returned in 1891 to the amount which it had reached in 1857, and with a much smaller fleet; that was due to the better utilization of the *materiel*, the length of the period of navigation being considerably extended. The number of trips of each boat has increased in the same ratio, while the tonnage carried per trip increased still more rapidly.

The average tonnage capacity of the boats now employed is 413 tons; the maximum tonnage per round trip is, then, 826 tons: in reality it is less, since, even when freight is plenty, the boats are less heavily loaded on the descent than on the ascent, for the purpose of limiting the enormous momentum which such masses acquire when they attain, as they do, at certain points, velocities of 22 to 24 km. per hour, and of making certain that the engine has sufficient power to overcome the velocity and stop the boat if occasion requires. With the improvement of the river, the straightening of the channel, which makes it possible to increase the distance between stops, and the reduction of the rapids, the difference between the loads for ascent and descent has very much diminished; the sum for ascent and descent is still considerably less than 826 tons, which is double the tonnage capacity.

In 1876, the tonnage was, at most, 450 tons; in 1880, it was 500 tons; 1885, 565 tons; 1887, 727 tons; 1889, 729 tons; 1891, 730 tons; that is to say, that for the last four years the degree of utilization appears to have practically attained its maximum.

The price of freight has naturally followed a downward path. Some comparative prices will permit of showing the reduction realized upon the goods which represent the greater part of the tonnage. The following table gives these figures:

Goods.	Route.	Price.		
		1876.	1884.	1892.
		Francs.	Francs.	Francs.
Metals	Lyons to Marseilles	12	11	9
Lime	Teil to Marseilles	11	7	6.50
Cereals	Marseilles to Dijon	26	22	17
Cereals	" Lyons	16	14	12.5
Vermicelli	" "	16	15	12.5
Wine	Cette and Marseilles to Lyons	17	16	14
Soap	Marseilles to Lyons	15	14	12
Sulphur	" "	14	13	11
Cordage	" "	22.5	16	12.5

There is, moreover, reason to hope that when the problem of traction upon the Rhône is solved, a problem of which a solution may be soon expected, the sacrifices made will not fail to bear fruit.

MARITIME NAVIGATION WORKS.

Section 1.—General Statement.

France is bounded by the sea upon three of the sides of the hexagon in which it is inscribed. Its shores have, excluding islands, a total length of 2 710 km., viz., 1st, 1 223 km. from the northern frontier to Audierne (North Sea and the English Channel); 2d, 862 km. from Audierne to Bidassoa (Atlantic Ocean); 3d, 625 km. from Cape Cerberet to Pont Saint Louis (Mediterranean). The number of ports, harbors and anchorages along these 2 710 km. of shore line is several hundred, at 200 of which there are works of maintenance upon State lands.

The object here is not to give an enumeration of the maritime works of France, but to give a glance at the improvements realized in these works in the course of the period included between January 1st, 1876, and December 31st, 1891, embracing, consequently, 15 years.

Naval *materiel* within half a century has undergone a transformation which has directly affected the accommodations of the ports of commerce. The dimensions of ships have increased in considerable proportions ; the number of steamships has increased in a progressive ratio, while that of sailing vessels has notably diminished. Sail navigation has regained some favor at this time, it is true, but the new sailing vessels are generally of dimensions comparable with those of steamers ; they are equipped with mechanical appliances for loading and unloading freight, as well as for the handling of sails and anchors. The increase in the dimensions of ships permits of realizing important economies in the cost of transportation as much from the point of view of the working force as from that of the *materiel*, and particularly in fuel. Thus the tendency to increase the tonnage of ships is thoroughly justified, and the increase will continue.

The heavy expenses due to steam vessels force efforts to avoid loss of time and to derive the greatest possible profit from the output. The time spent by ships in port thus decreases from day to day ; in order to reach this result it is necessary to create a plant which will permit of rapidly loading and unloading freight, and to develop railroads and navigable water-ways, which will serve purposes of transportation.

In order to satisfy these new wants, the ports have been forced to undergo modifications which permit them to receive ships much larger than those which frequented them formerly, and to save the time formerly lost by them before or after loading.

The writer will first attempt to show the improvements of a technical character made in this connection in the course of the 16 years which we are considering ; then, after a rapid glance at the expenses contracted in the accomplishment of this work, he will proceed to show the economic results which have been reached in the development of traffic.

Section II.—Technical Explanation.

Chapter 1.—Conditions of Access to Ports.

The channels giving access to a large number of ports have been improved and deepened. Calais, Boulogne and Dieppe, especially, have been put in a condition to receive, at the wharves of their outer ports, at all stages of the tide, the vessels which carry passengers between France and England. This improvement which greatly facilitates communication between the two countries, has principally been secured and maintained by means of dredges. The bottom of the channel in these ports is kept at an elevation varying between — 2.50 m. and — 4 m.* The annual dredging required to maintain this condition is not excessive, for the volume does not exceed 300 000 cu. m. for Calais, 200 000 for Boulogne, and 110 000 for Dieppe. The accommodations of the tidal docks in these three ports have also been improved, principally at Calais, where the passenger service is performed under very comfortable conditions. The channel has also been deepened by means of dredges, 2.70 m. at Dunkirk, and 1.80 m. at Ouistreham, etc. Furthermore, the excavation of a passage has just been finished across the bar of the Charpentiers (off shore from the mouth of the Loire) which will increase the available depth 1.40 m. for ships in foreign commerce and destined for St. Nazaire. The depths at the entrance of the ports at Tréport, Cherbourg, Les Sables, Bayonne and Cette have been in like manner increased.

Suction dredges, which raise a mixture of water and of sand, and let the sand settle in pits with gates, which are afterwards emptied into

* In each port, elevations are referred to the zero of the hydrographic charts, this zero corresponding to the level of the lowest tide observed. The minus sign is given to elevations below zero.

the sea, have greatly contributed to these results by reducing the cost of dredging. At Dunkirk, Calais and Boulogne, the dredging done by the Administration has cost only from 0.17 to 0.29 francs per cubic meter. Upon the bank of the Charpentiers, the dredging has been let to a contractor at 0.80 franc per cubic meter; the price will be much less when the Administration des Ponts et Chaussées has in operation the suction dredge which has just been ordered.

At Dieppe, on the contrary, the nature of the bottom, which is composed of limestone and a mixture of sand and gravel, requires the use of bucket dredges; and the cost amounts to 0.92 franc per cubic meter. This price is greater than that which they expect to pay at Havre with a dredge of greater power (its engine being of 500 H. P.) which has just been put in use.

Independently of dredging, other works have been undertaken at different points to improve the conditions of entrance into ports. At the entrance to Boulogne, the roadstead has been sheltered by the "Carnot" break-water founded in a depth of 8 m., and with a length of 2 110 m. Some dredging has been done for the purpose of increasing the sheltered surface where large ships can anchor. The entrance of the port of Cette has also been rendered safer by the extension of the break-water 850 m. to the east.

The inner channels of the ports of Dunkirk, Calais, Tréport, Dieppe, St. Valéry, Fécamp and Havre have been enlarged and at the same time straightened by the building of one and in some cases two jetties; they have also been deepened. These works greatly facilitate the movement of ships; furthermore, there is less danger of a ship's stranding, completely barring the channel, and entirely preventing egress or ingress, as had previously happened in certain cases.

The depths which have been attained in these different ports are, moreover, not considered as limits which will not be surpassed. On the contrary, an increase in depth of water is now anticipated, notably in the channels of approach to the ports of Dunkirk and Havre, and the time is approaching when the exterior passage and the channel included between the jetties in these ports will be excavated to from 4.50 to 5 m. below the lowest tides. The legislative difficulties which have so far retarded the execution of this programme seem about to disappear, so far as Havre is concerned.

As a result of the studies made by the Hydrographic Service of the

Navy for the purpose of discovering the proper means of rendering the port of La Rochelle accessible to the largest ships, the idea of improving the present port has been given up, and it has been decided to construct a new maritime establishment at La Pallice. This port, now opened to navigation, opens upon a roadstead of the first order, perfectly protected in every part. The outer port is excavated to the elevation — 5 m., so that the depth of water at high tide is between 9.65 and 11.55 m., and at low tide between 5 and 6.95 m. The depth in the basin is not more than 1 m. less than that in the outer port. The cost of establishing this new port has been but slightly increased by the rocky nature of the bottom, which is solid enough for foundations, and not solid enough to make the excavation very costly. The west coast of France has thus been provided with a safe and deep port; its absence had been regretted, and might have become serious under certain circumstances.

Flushing, which has for a long time been one of the principal means of maintaining the depth in channels, can no longer render real service under the new conditions; it has been almost wholly abandoned, notably at Dunkirk where the system was very fully developed, and has been replaced with advantage by dredging. But at Honfleur, with the special conditions of filling up which threatened this port, flushing has not only been maintained, but has been further developed, a new flushing basin having been built. Very ingenious and interesting arrangements have been adopted, in order to fill this basin at will exclusively with sea water during high tide, in order to prevent as much as possible the entrance of muddy water. The supply weir established for this purpose works excellently.

Chapter 2.—Interior Arrangements of Ports.

The interior arrangements of the ports have also undergone great modifications. The old works have generally been retained, but new ones have been constructed to receive large vessels, and satisfy the increase in traffic.

Nearly all the ports have been supplied either with new wet docks, or with deep-water quays. Wet docks have been constructed at Dunkirk, Calais, Dieppe, St. Valéry-en-Caux, Fécamp, Havre, Honfleur, Granville, St. Malo and St. Servan, Le Légue, St. Brieuc, Paimpol, St. Nazaire and Rochefort.

Tidal quays and open docks have been constructed at Boulogne, Tréport, Rouen, Caen, Calais, Lorient, Nantes, Les Sables-d'Olonne, and Bordeaux. The ports of the Mediterranean and of Algeria have also received noticeable improvements. Important works have been executed at Marseilles, Cette, Nice, Bastia, Ajaccio, Alger, Oran, Bone and Phillippeville.

Locks larger and deeper than those which have previously existed have been established in certain cases, in order to give ships sufficient access to basins. This has been the case notably at Cherbourg, Trouville, etc. The dimensions of the locks and the depths of basins and docks have been varied according to the types of ships which frequent the different ports. The width of the locks thus constructed has not been less than 30 m. at Havre, 25 m. at St. Nazaire and Dunkirk, 22 m. at La Pallice and 21 m. at Calais and Dunkirk. The most of them are provided with a chamber of large dimensions: 172 and 117 m. at Dunkirk; 167.50 m. at La Pallice; 150 m. at St. Nazaire, 133.50 m. at Calais; 100 m. at Fécamp.

The elevations of the lift wall are — 5 m. at Dunkirk; — 4 m. at La Pallice; — 1.75 m. at St. Nazaire and Calais, etc. The heights of the quay walls recently constructed have often been considerable, especially in the outer ports, where, at the same time, depressions have been excavated in which ships remain afloat at low tide. This arrangement has been adopted at Calais, Boulogne and Dieppe, as well as other places, for the packets in the service with England, and it is also found in the project adapted for Havre. The quay of the outer port of Calais is founded for part of its length at the elevation — 10 m., which gives it a total height of 19 m.

The construction of new works is often effected under particularly delicate conditions, on account of the nature of the bottom. The basin of Penhouet, at St. Nazaire, the third wet dock at Rochefort, and the quays of Bordeaux especially, have been founded in mud of great depth. Recourse has been had to the use of masonry wells, sunk by excavation through the shaft, as had previously been done at Havre and at the wet dock of Bordeaux. The inclination of the rock upon which the wells rested at St. Nazaire required its blasting into steps and the construction of masonry beneath the wells, which has considerably increased the difficulties of this work.

At Rochefort, the inflow of material beneath the wells has very

much hindered the foundation work. Under certain circumstances this sinking could be accomplished only by the use of compressed air. The shaft in the interior of the mass is in this case filled to a certain height with masonry save in the central portion, where a pipe is placed surmounted with an air chamber, serving for the extraction of the earth and the entrance of materials. The lower part of the shaft preserves its full dimensions and serves as a working chamber. Under these conditions, there is left remaining in the masonry only 350 kg. of iron per block. The excavation for the blocks was made by a water-jet, the earth, particularly at Calais, being composed of homogeneous sandy material.

The masonry blocks have often large dimensions in plan: 8 x 8 m. at Calais, and 10 x 6.70 m. at Havre. At Bordeaux, some blocks have been sunk 32 m. long by 6 m. wide. The descent is made very regularly by taking proper care, and blocks which have become inclined for any reason can be straightened up without difficulty. This mode of construction has even been employed with great success in works executed at points on the shore directly exposed to the sea. The jetties of Trouville and of Calais and part of the quays of the west dock of the Bellot basin were founded under these conditions.

Water-jets have also been employed on a large scale for sinking stone, and also wooden sheet piles, especially at Calais, Honfleur and Dunkirk. This method is very rapid and economical. At Calais the sinking of a section of sheet piling 1.80 m. to a depth of 2.50 m. was effected on an average in 1 hour and 10 minutes, while the driving with a hammer required 8 hours 30 minutes. The thickness of the sheet piling, moreover, could be reduced from 0.12 to 0.08 m.

Compressed air has been employed to a considerable extent in the execution of the works, because of the facilities which it offers and its relatively economical cost in permeable soils full of water. The jetties of Dunkirk were founded by this method, as well as the quay walls of Dunkirk, Calais, Boulogne, Fécamp and Bordeaux.

In the construction of the water barricades, iron is substituted in part for wood, which previously was alone employed; but the latter is still used almost exclusively in the construction of frame quays. Among the recent metallic barricades we may note those of Havre, Dieppe, Fécamp and St. Valéry-en-Caux. Metallic structures present important advantages as to strength and durability.

The gates of the locks are now constructed almost exclusively of iron. It is becoming more and more difficult to find timber which will give the rectangular cross section of the size required for gates of large dimensions. Iron gates are more rigid; the joints do not constitute the weak points as in wooden structures; the plating of iron gives to the structure a stiffness and invariability of form which cannot be obtained with wooden gates, in spite of the use of brackets, straps and bands. Moreover, metallic gates, by the use of air chambers conveniently placed and of sufficient dimensions, can bear at pleasure much or little upon the lower pivot, and the load remains practically constant, whatever may be the height of water at which the operations of opening and closing take place. They last much longer than timber work, and cost much less for locks of large dimensions. The reduction of cost was not less than 25% for the gates of the west lock of the Freycinet basins at Dunkirk, and 30% for the gates of the locks for transatlantic ships at Havre.

At Dunkirk, Havre, and several other places, a few gates are made up of vertical members bearing against an upper and a lower girder, instead of using a series of horizontal members. In this system, which is economical when the height approaches or is less than the length, the pressure is distributed very favorably. The sill supports the larger part of the load and the dimensions of the vertical members can be calculated exactly; on the contrary, in the system of multiple girders, one is obliged to make hypotheses, and to make up for the uncertainty of the methods of calculation, it is necessary to sensibly increase the dimensions in order to leave no doubt as to strength. Horizontal multiple girders, which are necessarily near together, render moving around and inspection in the interior compartments more difficult than vertical members; the latter divide the gate into passages in which one can move about easily.

The substitution of a single-leaf gate has, in some cases, been advocated for the double miter gates, which, up to a very recent time, were exclusively used for closing locks, in order to reduce the dimensions of the framework. The single leaf is easier to operate and does not present the same causes for wear and destruction as the double miter gates. These latter should be exactly of the same length as the miter-sill; they should, moreover, be always closed together and well placed relatively to each other, conditions which it is difficult to ful-

fill, especially in operating the gates of a lock in service, or when the sea is rolling.

The single leaf, on the contrary, always bears well upon the frame and sill, and it is easy to prevent the single leaf from striking by holding the free post by means of a bolt or hook. On the contrary, the use of gate hooks or springs only imperfectly prevents the striking of gates mitered against one another, and the deterioration which these repeated blows produce. Gates with a single leaf have been adopted for the locks of Tancarville and Fécamp, which are 16 and 18 m. in width of opening. It cannot be doubted that this system will become more general, having given the excellent results mentioned in these two cases.

The breakwaters and quays built in the Mediterranean have been constructed in enrockment of natural or artificial blocks, the handling of which has been facilitated by a special machine permitting the use of blocks of large dimensions.

Chapter 3.—Docking Apparatus.

In 1876, Marseilles, Havre, and Bordeaux were the only ports in France in which there were dry docks. In the other ports, the means of repair consisted almost exclusively of ways and pontoons for careening; wooden floating docks had, however, been established at Havre and Marseilles. Since that date dry docks have been constructed at Dunkirk, Calais, Dieppe, Havre, Cherbourg, Paimpol, St. Nazaire, La Pallice, Bayonne and Marseilles. Repairing slips have been built at Dunkirk, Bordeaux and Rouen.

Dry docks render the greatest service to navigation, and especially to iron ships, whose bottoms require frequent repainting. The docks at Dunkirk, Marseilles, La Pallice and Havre can receive the largest ships; they have lengths between 170 and 200 m. Their construction, which was relatively easy at St. Nazaire, La Pallice and Marseilles, where the material is rock, has presented great difficulties in other ports, an account of the nature of the earth and the abundance of springs. In order to put in foundations one has been forced to employ either masonry wells sunk by excavating through the shaft, as at Bordeaux, or caissons with compressed air, as at Bayonne. The walls usually have only a small number of offsets. The blocks, the height of which varies from 0.90 to 1.10 m., are metallic in the most recently constructed docks.

Pontoon gates have been preferred to abutting gates for closing the entrances to dry docks, as being tighter and occupying less length. The increase of time required to operate them, and the necessity of having a relatively large force of men, does not constitute a serious inconvenience, having given plenty of time, and the number of workmen necessary for these operations as well as for blocking up.

The apparatus for emptying is generally composed of two separate parts, one consisting of centrifugal pumps of large dimensions, designed for emptying the basin, the other consisting of centrifugal pumps or piston pumps indifferently, used for keeping it empty. The large docks of Dunkirk and of La Pallice, which contain 44 000 cu. m. of water each, can be emptied in three and a half hours, and those of Calais and Havre, which contain 32 000 cu. m., in three hours. Generally the steam engines operate the pumps directly; nevertheless, belts are used at Calais and St. Nazaire. The installation has been made so that the service may be assured in case of cleaning or repair of a boiler or engine.

Chapter 4.—Improvement of Maritime Rivers.

Considerable work has been undertaken on the Seine, the Loire and the Garonne, in order to facilitate the access of ships to the ports of Rouen, Nantes, and Bordeaux. On the Seine, the jetties commenced in 1848 have not been extended above Berville; but in the river, the banks have been straightened and important dredging has been done, notably across the bar of Meules, at Bardonville, the Ile-aux-Oiseaux, and Croisset. Independently of the recovery of over 20 000 hectares drained of water, the improvement of the Seine has given very satisfactory results to navigation.

Rouen formerly received boats of only 100 to 200 tons burden, having at most a draft of 3 to 3.50 m., and reaching there in about four days; to-day, boats having a draft of 5.50 m. arrive at its quays regularly at neap tide, and those of 7 m. at spring tide. The tonnage of ships entering, which was only 263 210 in 1861, and 418 100 in 1876, reached 1 211 435 tons in 1891. Ships now regularly ascend to Rouen on a single tide, but the descent requires two. The crossing of the estuary, which until recently could only be done by day, can now be done also by night, on account of the buoying of the channel with lighted buoys.

On account of the results obtained, the work of prolonging the dikes in the estuary is now progressing. The southern dike should be continued to Honfleur, the northern dike should stop about 3 km. above. This work and the removal of several shoals situated above in the river will result in an increase in the depth of water of almost 1 m. A law will be presented to the Chamber of Deputies for the purpose of authorizing the execution of this project.

Since boats for interior navigation cannot venture into the mouth of the Seine without risk of serious danger, a canal has been opened between Tancarville and Havre, in order to give them access to this port. This canal, which is 25 km. long, has a depth of 3.50 m. for the greater part of its length, and 6 m. as far as Havre. The structures are so built that this depth can be extended throughout the whole length. Locks with 16 m. openings and chambers 180 m. long and 30 m. wide, are placed at each extremity of the canal. Since the opening of this water-way inland boats arrive easily at Havre, without having anything to fear from the bar.

The Loire has been improved in such a manner as to allow access to the port of Nantes by ships drawing 5.50 m. The regimen of the river has been improved above by means of longitudinal dikes, and deepened above and below by means of dredging. But the depth of the intermediate portion included between the Carnet and the Martinière, in which are found numerous shallow places, apparently cannot be increased beyond 4.50 m., at least without excessive expense. It has therefore been decided to open a lateral canal, 15 km. long, to the right of this section; this canal is terminated at each end by locks of 18 m. opening, with chambers 100 m. long by 40 m. broad. The breadth of the basin is 24 m. at the bottom. It has been open to navigation since September, 1892, but the deepening of the Loire will not be finished until next year.

The improvement of the upper Gironde and of the maritime Garonne, from Pauillac to Bordeaux, which was begun a long time ago, has received a new impulse since the passage of the law of August 3, 1881, appropriating a sum of 30 000 000 francs for the execution of the works. The pass of the point of Ambés, which was one of the greatest obstacles to navigation, has been deepened, as has also the bar of Beychevelle; the Cazeau Isle and the Isle of the North have been removed, and the point separating the Garonne from the Dordogne has been reinforced

for 600 m. of its length. The depth of water on the pass above, which at low tide was only 0.90 m. in 1869, and 1.55 m. in 1888, is now more than 4 m. Upon the shoal of Beychevelle the dredgings have shown a ledge of soft rock, which reaches at some points to within 3.25 m. of low water-mark. A channel 100 m. wide presenting at least this depth is now open; it should be deepened to at least 4.50 m. or perhaps even to 5 m. below the level of ebb tide.

Dredging has been equally effective upon the bars of Carriette and of Bassens. The straightening of banks and dredging have been done with the object of unifying the direction of the flood and ebb currents in the channel of Bacalan. The depth of this passage below ebb tide which was only 2.50 m. in 1860, will soon be increased to 3.50 m. The improvement of the banks has also permitted giving Bordeaux a great length of wharf and of inclined slips for the loading and unloading of freight. The works have been carried on with a view to putting the passes of the Garonne into a condition to offer to large ships a safe and easy passage to the port of Bordeaux at all stages of the tide.

The jetties at the mouth of the Adour have been prolonged a little since 1876; there has resulted from it a new lowering of the bar, which is now 3.10 m. below the level of ebb tide. The jetties clearly seem now to have done all that one can attain by their use, and attention is being given to increasing the depths by dredging.

Chapter 5.—Wharf Equipment.

The Administration des Ponts et Chaussées attends only to the construction and maintenance of harbor works, their approaches and dependencies; it generally does not interfere with the location of railroads which are built by the railroad companies, nor with the public plant, properly speaking, shelters, store-houses, tools, etc., which are usually put up and operated by Chambers of Commerce, and sometimes by contractors. A certain number of navigation companies also possess plants which they use for their own particular needs.

The public plant amounted to almost nothing in 1876; it included only an occasional machine for loading and unloading, and some dock warehouses, of which only one, that of Marseilles, was conveniently provided with mechanical appliances for handling freight. Since this period great progress has been made. Special attention has been paid to improving the systems of navigable water-ways and that of the rail-

roads, and to putting them in direct communication with the basins and wharves of the maritime ports. Freight now arrives and departs much more rapidly and at less expense than formerly. The radius of action or of influence and the population served by ports have very much increased.

Tracks are built upon the quays in nearly all the ports, even those of the second order; they are placed according to circumstances, in such a manner as to permit either a direct transfer of freight from ships to car or conversely, or loading after inspection and delay upon the quay; or storage upon the quay before the arrival of the ship. In certain cases, the tracks are also used to facilitate the transfer of goods to storehouses after unloading from the ship.

Cranes and other hoisting apparatus have been put up in a number of ports, according to the importance and nature of the traffic. These machines are operated by hand, by steam or by hydraulic pressure; the use of electricity has been studied, but it has not yet been put in practice. Hydraulic pressure has been adopted, notably at Dunkirk, Calais, Havre, Rouen and Marseilles.

Sometimes cranes, instead of being placed on shore, are put on pontoons. This system, which presents certain advantages, has received its principal application at Rouen. Cranes of this nature are used at Havre, at Dunkirk and at Honfleur.

Quays provided with rails and with cranes have been used for the direct trans-shipment of coal and minerals at Dunkirk, Dieppe, Fécamp, Rouen, Le Havre, St. Nazaire and Bordeaux. Other quays have been arranged with reference to special traffic; but in most cases the quays have been arranged so as to satisfy in a general way the various needs of commerce. Tracks to the number of one, two or three are then placed along the quay walls, for use in direct trans-shipment between ships and cars; another system of two or three tracks is placed for a certain length along the road at the other edge of the quay embankment or platform. The large surface left between these two systems is used for storage and examination of freight which may be received and weighed. This surface is sometimes covered, particularly when the quay is used for the handling of valuable products such as wool, cotton, sugar, leather, etc.

The ports which are thus provided with sheds are daily increasing in number. Independently of large ports like Dunkirk, Calais, Havre,

Rouen, St. Nazaire, Bordeaux and Marseilles, there are also storehouses and shelters at Tréport, Dieppe, Caen, Les Sables, La Pallice, etc.

Aside from cranes of small power (from 1 250 to 1 500 kg.) serving for the loading and unloading of ordinary freight, there have been placed in the principal ports shears and engines for masting able to raise very heavy weights. There may be cited, among others, the shears at Marseilles, 120 tons; at Havre, 100 tons; at Nantes, 60 tons; at Bordeaux, 50 tons; at Dunkirk, 40 tons; and at Havre, Rouen and Dieppe, 30 tons. The most of these machines are fixed on shore; but some of them are floating, as the 40-ton crane at Dunkirk and the 80-ton at Havre.

Chambers of Commerce cover the cost of construction, maintenance and operation of the loading apparatus and buildings by means of taxes paid by those who use them, and in some cases by means of a tonnage tax, collected from all ships entering the port. This last system, which is resorted to when the direct tax is insufficient, exists at Dunkirk, Calais, Bologne, Dieppe, Rouen, Honfleur, Caen and Bayonne.

Chapter 6.—Lighthouses, Beacons and Sound Signals.

Within a few years some new lighthouses have been constructed, among which we may note the masonry lighthouses of Vieille (Finistère), of the great Cardinaux (Morbihan), of the great Charpentier (lower Loire), and Antifer (lower Seine). The first three are situated upon isolated rocks in the sea. A lighthouse built upon a metallic column on the pier head of Port Vendres is interesting on account of its peculiar construction.

Important improvements have been introduced in the apparatus, notably by the adoption of the super-radiant and flashlight systems. The super-radiant apparatus, or one of long focus, is 2.66 m. in diameter, and permits of increasing the light three-fold, that is to say, to the power of an apparatus of the first order. A light of this system has just been installed at Antifer.

The flashlights are characterized by flashes occurring at short intervals, and of short duration. Experience shows that there is no gain by prolonging the duration of the flash from a lighthouse beyond the minimum time necessary for the perception of the full inten-

sity, and further that there is a loss of light proportional to the excess of time. The maximum efficiency compatible with an optical apparatus of a given order is that obtained by flashing every 5 seconds, limiting the flash to the minimum time of complete perception, estimated at $\frac{1}{10}$ second, and in carrying the intensity of the emitted beams to a maximum. This last consideration requires the use of a single lens embracing a semi-circumference in plan, and, therefore, concentrating in a single beam half of the light emitted by the lamp. With a reflector having an efficiency which may be estimated at one-third, the other half of the light can be used in this system, and thus realize 0.83 of the total light. This combination realizes an efficiency which has never before been attained with flashing lights; but on account of the velocity of rotation which it requires (one turn in five seconds), it is necessary to give to the beam a large horizontal divergence. This requirement limits the employment of systems with a single lens to the fifth, fourth and third orders, if the dimensions of the six-wick burner, beyond which mineral oil lamps cease to be practical, cannot be exceeded. With two lenses, each embracing a semi-circumference, half of the total light is utilized, and the type can be applied to all orders.

The new system does not require the use of apparatus with four lenses, except for electric lights, in which the dimensions of the light are very small. Among the apparatus constructed on this principle there may be noted one of the fifth order with a diameter of 0.375 m. established at the lighthouse in the sea at La Teignouse, and a system of four lenses, having a focal length of 0.3 m., designed for the electric light north of La Hève. The intensity of the beam emitted by these lights is about 20 000 C. P. for the first, and 2 300 000 C. P. for the second.

Flashlights have necessitated the invention of a new mechanical combination in order to assure, by simple clockwork, the rapid rotation of the heaviest optical apparatus. This arrangement consists in carrying the optical part upon a floating ring resting in a dish of mercury of the same form. The pressure of the liquid is calculated to counterbalance the weight of the apparatus.

The most important lighthouses situated near great shoals, to the number of 13, will all be lighted by means of electricity. The transformation has already been made for 10 of them. Numerous

improvements have been introduced in the installation of the last electric lighthouses; optical apparatus permitting of an increase in the horizontal angle included by the lenses; an improvement of the rotating machine and its accessories; the employment of hot-air motors; modifications in the disposition of the machines and electrical regulators, as also the establishment of instruments of control. All these improvements, especially the organization of flashlights, have been designed and executed under the direction of M. Bernard, Inspector-General, by M. Bourdelles, the Chief Engineer of the Central Lighthouse Service.

The last electric lighthouses constructed, except that of La Hève, have been supplied with siren foghorns capable of instant operation by compressed air.

Permanent lights have been established at various points. After having tried gasoline at the turret of Lavardin, the use of ordinary mineral oil is now preferred. The results are satisfactory, and it is certain that the light will continue to burn, in good condition, without attendance, more than two months. A certain number of lights of this nature have been established, notably at Palais (Belle Isle), La Corne, St. Waast, the turret of the Morées (St. Nazaire), etc. This system seems appropriate for use in the lighting of jetties which are inaccessible for a long time, beacon towers, and points of secondary importance, which will not bear the expense of establishing and maintaining ordinary lighthouses.

Two lightships have been rebuilt on new designs, to replace those which were anchored near Dyck and Ruytingen, off the coast of Dunkirk. The stability of the ships has been determined in such a manner that the pendulum-like oscillations of rolling and pitching, in calm water, permit of no synchronism of their movement with that of the waves. The time of the rolling has been doubled, and its amplitude has been reduced one-half. The lights have been elevated, and the optical apparatus placed in a lantern sufficiently large to permit of the keeper looking after it without its being necessary to lower it upon the bridge as formerly. This apparatus has lights with a power which attains 1 200 C. P., while they did not exceed 48 C. P. in the old floating lights.

The floating light Ruytingen is supplied with a siren, working by compressed air.

The considerable cost which was occasioned by the establishment of floating lights, and especially the large expense required for their maintenance, has acted to restrain the use of these costly machines, and to replace them, as far as possible, by luminous buoys. These buoys necessitate relatively very small expense, and their number can consequently be multiplied, in order to reduce danger, or to indicate a route to be followed, more efficaciously and more economically than by the aid of lightships.

The buoys of the type called "a queue" are provided with lenses 0.20 to 0.30 m. in diameter, placed in the lanterns. The consumption per hour is from 20 to 30 liters of coal-gas, compressed to six atmospheres in the body of the buoy. The applications of this system of lighting become more numerous every day. Luminous buoys have been established at Minquiers, upon the shoal of Vergoyer, on the roadstead of Dunkirk, and to mark the channel of the Seine. Others will be placed in the Gironde and at the entrance of the Loire.

The number of luminous buoys in use on the coast of France is now 61 ; it will be nearly 100 at the end of the year 1893. The rapid development shown is the best demonstration of the value of this new method of lighting.

Section III.—Expenses and Traffic.

Chapter 1.—Expenses.

The maritime ports of France belong exclusively to the State. They have been constructed from the resources of its budget, and also in certain cases from local contributions, furnished by departments, cities, or chambers of commerce. The maintenance is wholly at the expense of the State.

	Francs.
The first cost of construction of maritime ports, from the 17th century to 1814, may be estimated at about	130 000 000
From 1814 to 1876 the cost reached	442 000 000
Total cost before 1876	572 000 000

The mean annual first cost of construction for the 52 years between 1824 and 1876 was only about 8 000 000 francs. Beginning with 1876, the annual expenses increased rapidly ; they exceeded 20 000 000

francs in 1877; they reached 52 000 000 francs in 1883, and have decreased since.

	Francs.
From 1876 to 1891, inclusive, there has been spent for the improvement of maritime ports a total of	522 600 000
The annual average for this period of sixteen years is thus	32 000 000

The greater part of these expenses has been taken from the national budget, supplied by the general tax. The users of a large number of ports have, however, been called upon to contribute to the expenses by means of special tonnage taxes, collected at the entrance of the ports. Parliament has a marked tendency to apply this system more and more. These local taxes are generally collected in each port, at the custom-house, for the benefit of the city or chamber of commerce, which is commissioned to furnish grants to the State for the execution of the works, the division having been fixed by the laws authorizing the works. The necessary funds for the grants are borrowed by the cities or chambers of commerce, and the lenders are reimbursed, both principal and interest, by means of taxes. The taxes cease to be collected when the reimbursement is completed. The amount of the subsidies thus furnished from 1876 to December 31st, 1891, was almost 80 000 000 francs. The amount of local taxes during the same period rose to nearly 56 000 000 francs.

For the division of the expenses and grants which we have just indicated in round numbers, by ports and groups of ports, the reader is referred to a table at the end of this paper, in which the conditions of the ports are presented for the years from 1876 to 1891, as to expense as well as to technical conditions of establishment and the movement of ships and traffic.*

We may especially mention here the subdivision of the expenses contracted from 1876 to 1891, by groups of ports, divided for the purpose into three classes. The traffic for 1891 has been taken as the basis for the classification. There is ranged, in the first class, commercial ports in which the traffic in 1891 exceeded 800 000 tonnage capacity (ships entering and departing); in the second class, commercial ports in which the traffic was between 80 000 and 800 000 tonnage

* In this connection, see annexed Table No. 1.

capacity ; in the third class, the small commercial ports and fishing stations, of which the traffic was less than 80 000 tonnage capacity.

The expenses are divided in the following manner :

	Francs.	Percent.
10 ports of 1st order.....	354 217 000	67.7
28 ports of 2d order.....	131 534 000	25.2
172 ports of 3d order.....	36 855 000	7.1
210 ports. Total.....	522 606 000	100

On collecting the figures for the tonnage capacity of loaded ships and those in ballast also, it will be found that this tonnage will be divided in the following manner between the same groups of ports :

	Tonnage Capacity.	Percent.
Ports of 1st order.....	33 438 000	76.3
Ports of 2d order.....	7 898 000	18.0
Ports of 3d order.....	2 500 000	5.7
Total	43 836 000	100

If we take account of the fact that the great ports have to serve multiple interests outside of the commercial traffic, such as that of passenger and mail service, and that the small ports constitute, also, a refuge for the innumerable fleets of fishing-boats of which the tonnage does not figure in the numbers given above, we will find that the expenses of first establishment are divided very exactly in proportion to the commercial importance of the port.

Chapter 2.—Movements and Traffic.

We shall distinguish in our statistics :

First.—Navigation along the coast between French ports.

Second.—Navigation from French ports to foreign, and conversely.

The coasting trade between French ports was represented in 1875 by a tonnage capacity of 7 950 000 tons (both arrivals and departures). This tonnage had increased in 1891 to 12 233 000 tons, and is a very noticeable increase.

The movement of navigation between French ports and foreign ports was measured by a total tonnage capacity (arrivals and departures of loaded ships and ships in ballast) of 16 717 000 tons in 1875,

and 31 603 000 tons in 1891. The total has increased, in round numbers, from 24 600 000 to nearly 44 000 000 tons.

The importance of foreign maritime commerce depends on the importance of the general commerce outside of the country. It will then be useful to give a glance at different periods to general commerce outside of France. A table will be found in the appendices to this memoir in which the movements of foreign commerce are brought together for the following dates: 1827, 1847, 1859, 1875, 1891, and where the figures are given relative to the movement of values, weights (at least since 1859), tonnage, separated into internal movements and maritime movements, importations and exportations, national flags and foreign.*

We will not here analyze this table previous to 1875. We note that in value as in weight, the maritime movement is always greater than the inland movement, and that it is undergoing a rapid extension. In 1875, the maritime movement, leaving out that of passengers and mail service, amounts to 11 320 000 tons of freight, valued at 6 101 million francs.

In 1891 these figures had reached respectively 20 894 million tons for freight, and 7 504 million francs for value.

Such figures suffice to justify the considerable expenses which France has contracted for the improvement of her maritime ports. But this analysis may be carried farther. The 11 320 000 tons of freight of foreign commerce were transported, in 1875, by ships of a total tonnage (both arrivals and departures) of 13 470 000 tonnage capacity (tonnage of loaded ships). If, to give the total movement, we add the ships in ballast, the tonnage is increased to 16 717 000 tons. In 1891, when the weight of freight had increased to 20 894 000 tons, the tonnage of ships loaded had increased to 25 136 000 tons, that of ships loaded and in ballast to 31 603 000 tons.

The substitution of steam vessels for sailing vessels has notably increased; as early as 1875, steamships represented a tonnage of 10 350 000 tons out of a total of 16 717 000 tons, or 62 per cent. In 1891, out of a total tonnage of 31 600 000 tons, steamships included 27 506 000 tons, or 87 per cent.

Not only do steam vessels include the total increase, but they have partially replaced sailing vessels. The preponderance of the use of

* See the annexed Table No. 2.

steam is also manifest in various ways according to the kind of navigation which is considered. Confining ourselves to European seas and to the basin of the Mediterranean, with a tonnage of 22 318 000 tons in 1891, steam navigation comprised 19 732 000 tons, or 88 per cent.

For long distances (commerce with French colonies not included), in a tonnage movement of 5 724 000 tons, steam navigation includes only 4 568 000 tons, or 79 per cent. In the commerce with Algiers and Tunis, the total tonnage is 2 900 000 tons; steam takes 2 852 000 tons—sail navigation is absolutely annihilated. In the commerce with the other French colonies steam navigation plays a role of much less importance, since in a tonnage of 530 000 tons, it takes only 358 000 tons.

It would no doubt be interesting to follow this analysis of the movement of our maritime commerce, but we will refer to a series of tables which can be found in the appendices at the end of this memoir.*

What has been said is sufficient to bring out a new characteristic of maritime navigation. The remarkable development of steam navigation coincides with the tendency to the concentration of maritime navigation in the hands of a few great companies. These lines themselves tend to substitute navigation in a circuit for direct navigation between two ports. A certain ship sailing at a fixed date completes its loading for a certain number of ports included within a certain radius. Upon its route and at its destination it takes on and discharges freight, and thus attains a reasonable utilization of a capacity enlarged for the purpose of reducing the general expenses per ton capacity.

In France, this tendency has been increased by the concession to a few companies of the monopoly of postal transportation, and of privileges in what relates to the transportation of passengers and ocean expressage. The annual subsidies given to these companies by the State now exceed 25 000 000 francs. Premiums for navigation by long voyages have also contributed to the development of regular lines of freight boats between France and North and South America, and the countries of the extreme east.

At the same time that regular lines and circuit navigation developed, it is rational to suppose that the capacity of ships would increase. This can be seen from the following table where, formed for showing

* See annexed Tables Nos. 3 and 4.

the increase in our exports, which divides ships by the kind of navigation. The comparison for the years 1875 and 1891 is for sailing vessels and steam vessel:

Kind of Navigation.	Average Capacity.			
	In 1875.		In 1891.	
	Sail.	Steam.	Sail.	Steam.
	Tonnage.	Tonnage.	Tonnage.	Tonnage.
European Seas, except Algeria	121	333	195	515
Algeria	160	525	160	713
Seas outside of Europe, except the Colonies	432	1 671	696	1 987
Colonies	318	644	385	1 500

We see that the increase of average capacity is considerable. This increase is especially remarkable for steamships, and particularly for the navigation of seas outside of Europe.

In order to complete the account of the transformation which maritime navigation has undergone, the effect of which has reacted upon our ports and has necessitated the important works considered above we believe that it will be equally interesting to note the modifications which have been effected in the French ships attached to our ports. These modifications moreover confirm the observations made at the time on the movements of ships, in arrival and departure.

Coasting Trade Between French Ports.—In 1875, the number of sailing vessels employed in the coasting trade was 2 460, the total tonnage capacity being 96 927 tons; the average tonnage was 39 tons. The number of steam vessels engaged in the same service was 144, with a total tonnage capacity of 12 859 tons and the average tonnage was 89 tons. In 1891, the number of sailing vessels had decreased to 1725, with a tonnage capacity of 86 319 tons and an average tonnage of 50 tons. The number of steam vessels had increased to 145, with a total tonnage capacity of 13 773 tons, an increase of one vessel and 914 tons. The average tonnage had increased to 95 tons.

Navigation of the European Seas and of the Mediterranean.—In 1875, the number of French sailing vessels was 893, with a tonnage capacity of 45 197 tons, and an average tonnage of 51 tons. The number of French steamers was 152, with a total tonnage capacity of 78 476 tons and an average of 516 tons. In 1891, the number of sailing vessels had

decreased to 280, with a tonnage capacity of 53 526 tons and an average of 191 tons. The number of steam vessels has increased to 290 and the tonnage capacity to 165 985 tons, gaining 98 ships and 87 509 tonnage. The average capacity has increased from 191 to 664 tons.

Navigation of Seas Outside of Europe.—In 1875 the number of French sailing vessels was 1 084, with a tonnage capacity of 338 261 tons, and an average tonnage of 312 tons. The number of French steamships was 78, with a tonnage capacity of 97 865 tons and an average of 1 255 tons.

In 1891, the number of sailing vessels had decreased to 324 with a tonnage capacity of 136 574 tons and an average of 421 tons, an appreciable increase over the average of 1875. The number of steamships had increased to 187 and the tonnage capacity to 319 279 tons, gaining 109 ships and a tonnage of 217 414 tons.

At the same time with the average capacity, the dimensions of ships in length, in breadth and in depth, have undergone a considerable increase. The averages it will not be worth while to give here, but if reference is made to the data upon steamships published by the Bureau Véritas, it may be noted among the fleets of the transatlantic companies ships with dimensions exceeding 160 m. and even 188 m. in length, 20 m. in breadth and 9.50 m. draft.

In view of the necessity of serving a constantly increasing traffic under the conditions indicated above, and of permitting the entrance of ships whose dimensions are continually increasing, it is evident how urgent is the necessity of adapting our ports to these new requirements.

By referring to the annexed Table No. 1, it will be seen that the depths at the entrance and in the channels of our principal ports have been sensibly increased. The useful lengths of the quays, which in 1876 amounted to 139 732 m., have increased to 194 428 m. These figures are destined to increase rapidly. The proportional increase is, moreover, much more considerable than the absolute figures seem to indicate, for it has taken place almost exclusively in ports of the first order, where the lengths are doubled. Moreover, the equipment works have had the effect of increasing the use and efficiency of the port.

CONTENTS.

PAGE

Preface 1

INTERIOR NAVIGATION WORKS.

SECTION I.—GENERAL STATEMENT 3

SECTION II.—TECHNICAL CONSIDERATIONS :

Chapter 1.—Construction of New Water-Ways 7

Chapter 2.—Improvement of Existing Water-Ways 12

Chapter 3.—Traction 22

SECTION III.—EXPENSES AND TRAFFIC :

Chapter 1.—Expenses. General Considerations 27

Chapter 2.—Traffic. General Considerations 28

Chapter 3.—The Seine 33

Chapter 4.—Principal Line from Paris to Belgium 36

Chapter 5.—System of the North and of Pas-de-Calais 38

Chapter 6.—Line from Paris to the East 39

Chapter 7.—Canal of the East 41

Chapter 8.—Water-Ways Connecting the Canal of the East with the Lines from Paris to Belgium, and from Paris to the East 41

Chapter 9.—The Saône, from Corre to Lyons 43

Chapter 10.—The Rhône, from Lyons to St. Louis 44

MARITIME NAVIGATION WORKS.

SECTION I.—GENERAL STATEMENT 47

SECTION II.—TECHNICAL EXPLANATION :

Chapter 1.—Conditions of Access to Ports 48

Chapter 2.—Interior Arrangements of Ports 50

Chapter 3.—Docking Apparatus 54

Chapter 4.—Improvement of Maritime Rivers 55

Chapter 5.—Wharf Equipment 57

Chapter 6.—Lighthouses, Buoys and Sound Signals 59

SECTION III.—EXPENSES AND TRAFFIC :

Chapter 1.—Expenses 62

Chapter 2.—Movements and Traffic 64

APPENDICES :

No. 1.—Conditions of Improvement and Access, Development of Quays and Cost of Establishment of New Maritime Ports of Commerce to January 1st, 1892 71

CONTENTS—(*Continued*).

PAGE

No. 2.—Foreign French Commerce. Years 1891, 1875, 1859, 1847 and 1827..... 78

No. 3.—Maritime Commercial Movement of France with Foreign Countries and the Colonies, Year 1875..... 79

No. 4.—Maritime Commercial Movement of France with Foreign Countries and the Colonies, Year 1891..... 88

NOTE.— Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

Direction of Roads, of Navigation and of Mines.—Conditions of Working and of Access.—Development of Quays and Cost of Works for Maritime Commercial Ports to January 1st, 1892.

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and outbound).	Goods traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN. **1st. Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.**																	
1 Havre	3 699 233 5 945 923	2 081 894 3 383 069	189 106 (a)	9.85 9.85 (b) 12.35	7.90 7.90 (b) 10.40	2.30 2.30 (b) 4.80	8 000 11 565 (b) 12 065	654 1 985 (b) 2 385	8 654 13 550 (b) 14 550	95 000 000	68 324 988	(c) 163 324 988	3 000 000	1894	(d) 13 694 000	(e) 0.65 franc per ton on foreign vessels or on on French vessels coming from foreign ports; 0.30 franc when these vessels are loaded with coal, white pine or ice, in the proportion of 9 to 10.	17 623 665
2 Bordeaux	2 352 934 3 527 210	1 866 300 2 582 471	14 350 29,679	In the channel (a) 7.65 8.50 8.86 At the entrance of the road- (b) 7.60 9.14 9.36	5.69 6.19 6.55 stead of Bordeaux. 5.64 6.83 7.05	2.50 3.24 3.60 2.45 3.88 4.10	(c) 1 107 3 350 4 302	....	(c) 1 107 3 350 4 302	21 412 828	42 238 145	(d) 63 650 973	(d) 20 150 600	(e)	(f) 10 000 000	(g) 0.60 franc (law of August 2d, 1887).	(h) 5 606 626
3 Dunkirk	1 360 454 3 180 311	1 155 600 2 609 958	4 976 5 087	6.00 8 60 8.60	4.25 6.85 6.85	0.10 2.80 2 80	1 675 7 266 7 266	900 900 900	2 575 8 166 8 166	(a) 38 000 000	66 000 000	104 000 000	28 000 000	(b) 1895	(c) 7 500 000 (d) 4 600 000	0.64 franc per ton of capacity (law of September 1st, 1884, and decree of August 26th, 1890). 0.16 franc per ton of capacity (decree of August 26th, 1890).	(e) 8 946 441 492 261
4 Rouen	878 064 2 491 485	894 058 2 062 309		Channel of access between Rouen and the sea. 7.20 7.40 7.40 Port 7.00 8.50 9.00	5.30 5.50 5.50 (a) 5.00 6.66 7.15	0.40 0 60 0.60 3.85 5.45 5.95	3 528 4 994 5 940	....	3 528 4 994 5 940	(b) 22 645 409	(b) 28 867 272	(b) 51 512 681	(b) 9 338 388	.....	(c) 6 837 667	0.55 franc.	5 334 917
5 St. Nazaire	710 647 1 698 588	501 196 1 292 325	....	8 80 8.80 (a) 10 50	7.00 7.00 (a) 8.70	3.30 3.30 (a) 5.00	1 606 4 275 ..... 4 275	.... 103 103	1 606 4 378 ..... 4 378	18 798 548	17 427 298	36 225 846	(b) 2 500 000	1895	(c) 3 330 000	(d) 0.60	(e) 1 519 801
6 Boulogne	871 359 1 563 527	435 628 532 044	13 500 44 705	Interior port. 7.65 (a) 12.90 (b) 12.65 Exterior port. (c) 16.90	5.00 (a) 10.28 (b) 10.03 (c) 14.28	0.90 (a) 4 36 (b) 4.11 (c) 8.36	1 248 2 038 2 038 (d) 1 000	1 467 880 880	2 715 2 918 2 918 (d) 1 000	14 000 000	23 430 000	37 430 000	15 370 000	.....	(e) 5 932 896	(f)	3 002 631
7 Calais	844 566 1 376 481	265 388 426 266	2 390 1 910	7.25 10.00 11.00	5.35 8.10 9.10	0.25 3.00 4.00	(a) 765 (b) 3 275 (c) 3 470	1 450 1 450 1 450	2 215 4 725 4 920	10 000 000	42 520 000	52 620 000	3 155 000	1895	(d) 4 250 000	Passenger vessels 0.06 franc per ton of capacity. Merchant vessels 0.30 franc per ton of capacity, plus 1.75 franc per passenger going or coming (laws of January 1st, August 7th, 1884, and October 4th, 1888).	4 375 618

The notes to which reference is made may be found on the pages following the table.

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated. }

APPENDIX No. 1—(*Continued*).

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and outbound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN. **1st. Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.**																	
[8] Dieppe	**814 668** 1 017 732 ..... 11.67	**589 930** 670 766 ..... 8.97	**6 050** 6 513 ..... 2.50	**7.67** 11.67 11.67 8.97	**4.97** 8.97 8.97 2.50	..... 2.50 2.50 2.50	**1 900** 2 780 2 780 1 150	**800** 1 118 1 150 3 930	**2 700** 3 898 3 930 3 930	19 800 000	19 400 000	39 200 000	(a) 2 100 000	1894	(b) 6 422 777	0.30 franc per ton of capacity plus 1 franc per passenger going or coming (law of August 3d, 1884).	2 982 630
Total for the principal ports	**11 501 915** 20 741 248 ..... 43 136	**7 789 994** 13 559 287 ..... 6 868	**41 455** 87 900 ..... 50 004	.... 6 868	.... 6 868	.... 50 004	**19 829** 39 543 43 136 6 868	**5 271** 6 436 6 868 45 979	**25 100** 45 979 50 004 50 004	239 656 785	308 207 703	547 864 488	83 613 388	.....	61 467 340	.....	49 884 590
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN—(*Continued*). **2d. Port of second order, having in 1891 a traffic between 80 000 and 800 000 tonnage capacity.**																	
[9] La Rochelle — Port Proper	**361 654** 613 647 ..... 6.53	**258 945** 347 026 ..... 5.03	(a) **2 882** 3 913 ..... 1.88	**6.38** 6.53 6.53 5.03	**4.88** 5.03 5.03 1.88	**1.73** 1.88 1.88 1.88	**1 363** 1 710 1 710 752	**752** 752 752 2 462	**2 115** 2 462 2 462 2 462	9 000 000	(b) 220 000	9 220 000	620 000	1895		0.25 franc (decree of August 19th, 1880).	438 244
[9] La Rochelle — Port of La Pallice	162 784 ..... 10.80	48 021 ..... 9.30	.... 6.15	10.80 10.80 10.80	9.30 9.30 6.15	6.15 .... 1.600	1 600 1 600 510	(c) 510 2 110 2 110	2 110 2 110 2 110	.....	20 910 000	20 910 000	1 590 000	1894	(d) 1 800 000		
[10] St. Malo, St. Servan	**458 071** 545 274 ..... 9.50	**252 479** 348 206 ..... 4.60	**2 119** 1 300 ..... 4.60	**9.50** 9.50 9.50 4.60	**4.60** 4.60 4.60	....	**2 209** 2 493 2 493 792	..... 792 792 3 285	**2 209** 3 285 3 285 3 285	17 798 000	11 631 000	29 429 000	393 000	1894	600 000	0.25 franc, sailing vessels; 0.30 franc, steamers; 0.10 franc, packet boats (decree of April 26th, 1886).	(b)
[11] Bayonne	**157 454** 438 248 ..... 6.70	**146 465** 555 559 ..... 6.00	**179** 695 ..... 3.65	**5.53** 6.28 6.70 6.00	**4.73** 5.48 6.00 3.65	**2.38** 3.13 3.65 3.65	**1 080** 2 060 2 170 2 170	....	**1 080** 2 060 2 170 2 170	9 611 000	4 998 000	14 609 000	593 000	1896	(a) 124 000		
[12] Rochefort	**225 258** 411 563 ..... 11.12	**183 490** 364 681 ..... 8.93	.... 5.88	**11.12** 11.12 11.12 8.93	**8.93** 8.93 8.93 5.88	**5.88** 5.88 5.88 5.88	**750** 1 915 1 920 890	**890** 890 890 2 805	**1 640** 2 805 2 810 2 810	3 775 709	13 681 000	(b) 17 366 709	115 000	1893	2 242 012	0.26 franc.	106 843
[13] Caen-Ouistreham — Port of Caen	**280 578** 408 800 ..... 7.40	**258 771** 443 057 ..... 5 80	**271** 360 ..... 2.10	**4.30** 4.90 7.40 5 80	**3.00** 4.00 5 80 4.00	**0 30** 0.30 2.10 0.30	**1 320** 1 820 1 820 300	**300** 300 300 2 120	**1 620** 2 120 2 120 2 120	11 940 341	3 997 321	15 937 662	40 000	1893	(a) 779 000		
[13] Caen-Ouistreham — Outer port of Ouistreham				**5.92** 6.20 7.70 6.10	**4.00** 4.60 6.10 2.40	**0.30** 0.90 2.40 2.40											
[14] Honfleur	**475 116** 400 308 ..... 6.60	**224 675** 281 598 ..... 4.50	**430** 430 ..... 1.00	**6.60** 6 60 6.60 4.50	**4.50** 4.50 4.50 1.00	**1.00** 1.00 1.00 1.00	**1 362** 2 206 2 205 1 800	**1 200** 1 800 1 800 4 005	**2 562** 4 005 4 005 4 005	8 861 000	9 547 400	18 408 400	.....	.....	2 848 020	0.25 franc.	1 426 560
[15] Nantes	**379 797** 380 989 ..... 6.50	**448 568** 469 100 ..... 5.20	**591** 612 ..... 2.80	**4 60** 6 00 6.50 5.20	**3.20** 4.70 5.20 2.80	**1.00** 2.30 2.80 2.80	**6 446** 7 926 8 226 8 226	....	**6 446** 7 926 8 226 8 226	2 254 682	(a) 28 872 000	31 126 682	2 630 000	1893	970 000	0.10 franc per ton of capacity for foreign vessels or for French vessels coming from foreign ports.	(b) 210 100
[16] Cherbourg	**512 386** 371 531 ..... 8.00	**135 935** 243 618 ..... 6.34	**202** 485 ..... 2.15	**6.50** 8.00 8.00 6.34	**4.84** 6 34 6.34 2.15	**0.65** 2.15 2.15 2.15	**8.10** 8.70 8.70 655	**655** 655 655 1 525	**1 465** 1 525 1 525 1 525	2 914 500	3 838 622	6 763 122	406 680	1895	909 233	0.30 franc per ton of capacity for all vessels loaded or coming to take load at the port. Rate reduced to 0 15 franc for vessels of less than 100 tons and for those doing regular service between Cherbourg and a foreign port.	(b) 326 382

NOTE.—Figures like this { 7·20 / 7 40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

APPENDIX No. 1—(*Continued*).

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and out-bound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1875 to 1891, inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN—(*Continued*). 2d. Ports of second order, having in 1891 a traffic between 80 000 and 800 000 tonnage capacity.																	
[17] Brest	**189 773** 364 846 221 651	**135 061** 221 651 790	**963** 790	**13.50** 14.50 14.50	**11.30** 12 30 12.30	**6.50** 7.50 7.50	**1 625** 1 625 1 625	**695** 695 695	**2 320** 2 320 2 320	17 446 652	2 131 286	19 577 938	(a) 3 680 000				
Tonnay Charente	**209 697** 177 315 183 346	**195 504** 183 346		**9.32** 9.32 9.32	**7.13** 7.13 7.13	**4.08** 4.08 4 08		**1 120** 1 170 1 170	**1 120** 1 170 1 170	882 138	99 008	981 146					
Lorient	**93 588** 157 931 86 495	**78 510** 86 495	**11** 440	**5.30** 5.30 5.30	**3.85** 3.85 3.85	**0.75** 0.75 0 75	**735** 785 785	**310** 310 310	**1 045** 1 095 1 095	3 001 629	290 618	3 292 247					
[18] Les Sables	**105 193** 151 356 142 302	**123 510** 142 302	**2 032** 2 400	**4.40** 5.60 5.60	**3.10** 4.30 4.30	**0.60** 1.60 1.60	**432** 674 674	**1 155** 1 160 1 160	**1 587** 1 834 1 834	8 130 041	4 219 809	12 349 850	258 548	1893	(a) 63 449		
[19] Trouville	**81 033** 139 109 114 880	**70 149** 114 880	**928** 1 072	**5.60** 6.50 6 50	**3.64** 5.10 5.10	**0.50** 1.80 1.80	**680** 1 010 1 010	**945** 561 561	**1 625** 1 571 1 571	4 086 000	2 433 315	6 519 315	400 000	1893	(a) 926 000	0.50 franc.	116 644
[20] Tréport	**47 139** 135 934 149 574	**35 377** 149 574	**3 250** 2 370	**5.42** 6.90 6.90	**2.95** 4.20 4.20	…… …… ……	**7 flying bridges.** 7 flying bridges. 4 large flying bridges.	**410** 560 560	**440** **7 flying bridges.** 560 7 flying bridges. 560 4 large flying bridges	2 900 000	4 100 000	7 000 000	2 050 000	1896	1 793 000	0.30 franc per ton of capacity from June 1st, 1885, to April 7th, 1891 (decrees of May 6th, 1885; August 25th, 1888; October 28th, 1889, and May 4th, 1890). 0.55 franc per ton of capacity (decree of April 28th, 1892).	100 620
[21] Granville	**129 065** 134 789 75 635	**62 273** 75 635	**4 391** 2 429	**9.60** 9.60 9.60	**5.60** 5.60 5.60	…… …… ……	**985** 1 060 1 060	**671** 671 671	**1 656** 1 731 1731	7 324 240	1 118 606	8 442 846	……	……	124 900		
[22] St. Martin de Rue	**135 020** 119 193 24 902	**44 053** 24 902	……	**4.20** 4.70 4.70	**3.20** 3.70 3.70	…… …… ……	**574** 601 601	**400** 436 436	**974** 1 037 1 073	786 981	526 926	1 313 907	2 000	1893	30 000		
[23] Blaye	**49 691** 117 075 31 753	**30 955** 31 753	……	**3.46** 3.46 3.46	**2.05** 2.05 2.05	**— 2.00** — 2.00 —2.00	…… …… ……	**6.00** 6.00 6 00	**6.00** 6 00 6. 0	244 000	5 200	249 200					
[24] Fécamp	**80 282** 101 366 95 352	**75 362** 95 352	**4 950** (a) 16 311	**9.40** 9.40 9.40	**7.40** 7.40 7.40	**1.50** 1.50 150	**760** 1 220 1 520	**380** 420 520	**1 140** 1 640 2 040	(b) 13 470 000	8 040 132	21 510 132	1 000 000	1894	(c) 1 475 000	(d) 0.75 franc per ton of capacity on vessels loaded or coming to load in port.	(e) 291 372
Le Legua	**59 305** 83 645 69 684	**54 388** 69 684	**137** 175	**8.75** 6.25 5.05	**6.00** 3 50 2.30	…… …… ……	**3.70** 3.70 3.70	**1 500** 1 500 1 500	**1 870** 1 870 1 870	1 870 000	785 000	2 665 000	34 600	1893	159 800	0.40 franc.	59 549
Total for ports of the second order	**4 030 100** 5 415 703 4 286 440	**2 814 470** 4 286 440	**23 339** 33 575	……	……	……	**21 502** 29 944 30 654	**11 983** 13 782 13 882	**33 484** 43 726 44 536	126 196 913	121 345 243	247 542 156	13 812 828	……	14 844 414	…… ……	3 126 314

The notes to which reference is made may be found on the pages following the table.

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated.

APPENDIX No. 1—(*Continued*).

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and out-bound).	Goods, traffic (in tons of 1 000 kg.)	Total quantity of fish received (in tons of 1 000 kg).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891 inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I. PORTS OF THE ENGLISH CHANNEL AND THE OCEAN—(*Continued*).																	
3d. Ports of third order and fishing stations.																	
All the ports of 3d order and fishing stations	2 237 287 1 841 847	1 336 739 1 152 753	39 600 23 232	.....	.....	.....	10 386 13 644 13 729	35 596 46 030 46 333	45 982 59 674 60 062	73 629 639	31 381 107	105 010 746	1 850 703	.....	2 841 629	.....	87 506
Total for ports of the English channel and the ocean.	17 769 302 27 998 798	11 911 203 19 008 480	104 394 144 707	.....	.....	.....	51 716 83 131 87 519	52 850 66 248 67 083	104 566 149 379 154 602	439 483 337	460 934 053	900 417 390	99 276 919	.....	79 163 383	.....	53 098 410
I. PORTS OF THE MEDITERRANEAN.																	
1st. Mainland.—Principal ports, having in 1891 a traffic of over 800 000 tonnage capacity.																	
25 Marseilles	5 365 345 10 610 719	3 322 421 5 251 648	557 1 096	.....	.....	(a) 7.00 7.00 7.00	.....	.....	(b) 8 564 13 167 13 167	(c) 62 761 408	(c) 32 202 623	(c) 94 953 931	1 930 511	1893	(d)		(e) 1 979 193
26 Cette	999 574 2 085 681	703 982 893 475	1 423 1 128	.....	.....	6.00 (a) 7.00 7.00	.....	.....	6 600 (b) 8 703 8 703	19 300 000	13 806 706	33 106 706	(c) 11 600 754	1895	(d) 675 000	(e) 0.05	(e) 856 345
Total for the principal ports	6 364 929 12 696 300	4 026 393 6 145 123	1 980 2 224	.....	.....	.....	.....	.....	15 164 21 870 21 870	82 051 408	46 009 229	128 060 637	13 491 265	.....	676 000	.....	2 835 638
II. PORTS OF THE MEDITERRANEAN—(*Continued*).																	
1st. Mainland.—Ports of second order, having in 1891 a traffic of over 80 000 and less than 800 000 tonnage capacity.																	
Nice	210 104 466 437	88 869 187 856	185 50	.....	.....	6.50 6.60 6.50	.....	.....	840 1 320 1 320	477 644	3 972 024	4 449 668					
Port Vendres	67 743 362 833	35 741 81 714	4 4	.....	.....	14 000	.....	.....	741 811 811	3 796 673	1 038 639	4 836 212	267 368	1897			
St. Louis-on-the-Rhône	360 656	246 833	19 31	.....	.....	6.00 6 30 5.30	.....	.....	1 765 1 765 1 765	14 380 463	925 924	15 306 387					
La Ciotat	162 488 235 437	10 308 19 816	201 124	.....	.....	6 00 6.00 6.00	.....	.....	200 200 200	639 000	689 081	1 228 081	3 067				

The notes to which reference is made may be found on the pages following the table.

NOTE.—Figures like this { 7·20 / 7.40 / 7·40 } correspond to { 1876. / 1891. / contemplated. }

APPENDIX No. 1—(*Continued*).

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and outbound).	Goods traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total, including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
II. PORTS OF THE MEDITERRANEAN—(*Continued*).																	
1st. Maiuland.—Ports of the second order, having in 1891 a traffic of over 80 000 and less than 800 000 tonnage capacity.																	
Toulon — Old wet dock	**64 973**	**42 863**				**5·80**			**504**	250 000	68 000	1 141 719					
						5,80			504								
						5·80			504								
Toulon — Roadstead						**5·50**			**737**	833 719							
	201 510	58 342	159			5.50			737								
						5·50			737								
[2] Bone	**79 655**	**65 275**	**36**			**6.00**			**650**	1 773 347	459 317	2 232 664	4 163 683	(a)			
	130 900	111 048	8			6.00			650								
						9·00			650								
[2] Cannes	**57 551**	**39 809**	**54**			**6.00**			**370**				849 314	1896	(a)	0.35 franc (law of October 10th, 1891).	
	92 994	44 855	80			6.00			370								
						6·00			370								
Total for the ports of second order	**612 514**	**282 865**	**50**						**5 807**	22 050 746	7 142 885	29 193 631	5 283 422				
	1 850 767	749 470	447						6 357								
									6 357								
3d. Ports of third order and fishing stations.																	
All the ports of 3d order and fishing stations	**587 210**	**344 020**	**2 183**						**42 933**	20 212 852	720 405	24 993 257	252 488		131 801		
	449 227	315 411	5 423						14 876								
									14 879								
Total for the ports on Mediterranean maiuland	**7 594 653**	**4 653 278**	**4 605**						**33 904**	124 315 006	57 872 519	182 187 525	19 027 175		806 801		2 835 538
	14 996 344	7 210 004	8 094						43 103								
									43 106								
§ 2. Corsica.																	
Bastia — Old port	**258 342**	**42 825**	**262**			**10.50**			**250**	1 408 426	3 100	1 411 526					
						10·50			250								
						10·50			250								
Bastia — New port						**8·50**			**100**	3 090 504	2 514 125	5 604 629	19 741	1893			
	367 689	36 098	180			8,50			360								
						8·50			360								
Ajaccio	**179 703**	**38 296**	**151**			**12.00**			**150**	2 208 072	528 170	2 736 242	122 087	1893			
	263 816	77 663	110			15,00			235								
						15·00			440								

NOTE.—Figures like this { 7.20 / 7.40 / 7.40 } correspond to { 1876. / 1891. / contemplated. }

APPENDIX No. 1—(*Continued*).

Designation of the ports (arranged in order of importance).	Total tonnage capacity (inbound and out-bound).	Goods, traffic (in tons of 1 000 kg.).	Total quantity of fish received (in tons of 1 000 kg.).	Minimum depth of water at entrance and in the channel.			Length of useful quay (in meters).			Expenses for works of construction and improvement (in francs).					Subsidies given to the State (in francs).		
				At high water of mean spring tide.	At high water of minimum neap tide.	At low water of minimum spring tide.	Full depth of water.	Shallow water.	Total.	Incurred before 1876.	Incurred from 1876 to 1891.	Total including 1891.	Remaining to be done for the completion of the works declared of public benefit.	Probable date of completion.	Subsidies given or to be given by cities, departments and Chambers of Commerce for works of improvement executed since 1876.	Existing tonnage duties granted in return for these subsidies.	Total receipts from tonnage duties from 1876 to 1891, inclusive.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
§ 2. Corsica—(*Continued*).																	
Other ports	207 230 209 385	42 820 33 692	145 184						762 1 101 1 101	1 718 156	753 852	2 224 405	749 997		15 000		
All the ports of Corsica	645 275 840 890	123 941 147 453	558 474						1 262 1 946	8 425 158	3 799 247	12 224 405	891 825		15 000		
III.—RECAPITULATION.																	
I.—Ports of the ocean and English channel	17 767 302 27 998 798	11 941 203 19 008 480	101 391 141 707						101 566 149 379 154 602	439 483 337	460 934 053	900 417 390	99 276 919		79 153 383		53 098 410
I.—Ports of the Mediterranean. § 1. Mainland	7 594 653 14 996 344	4 653 278 7 210 004	4 605 8 094						33 904 43 103 43 106	124 315 006	57 872 519	182 187 525	19 027 175		806 801		2 835 538
I.—Ports of the Mediterranean. § 2. Corsica	645 275 840 890	123 941 147 453	558 474						1 262 1 946 2 151	8 425 158	3 799 247	12 224 405	891 825		15 000		
Grand total	26 009 230 43 835 032	16 718 422 26 365 937	109 557 153 275						139 732 194 428 199 859	572 223 501	522 605 819	1 094 829 320	119 195 919		79 975 184		55 933 948

REMARKS ON APPENDIX No. 1.

[1] HAVRE—

(*a*) Besides, 3 460 000 oysters and 3 000 000 scallops.

(*b*) These figures are what should be realized on the completion of the basin for petroleum now in construction, and when the improvement works are carried out.

(*c*) This includes the sum of 24 300 000 francs for the construction of the Tancarville Canal.

(*d*) 1st. Port of Havre.

	Francs.
Construction of the Bellot Basin and of two dry docks:	
Chamber of Commerce	4 011 000
Department	1 500 000
Dredging off shore:	
Chamber of Commerce	545 000
Dredging plant:	
Chamber of Commerce	890 000
Construction of a petroleum basin:	
Chamber of Commerce	600 000
Deepening of the Vauban Basin:	
Chamber of Commerce	50 000
Other sources	16 000
Rebuilding of the dock bridge:	
Chamber of Commerce	20 000
Company of the Western Railroads	30 000
Total for the Port of Havre	7 662 000

2d. Tancarville Canal.

Construction of the canal:	
Chamber of Commerce	6 000 000
City of Havre	32 000
Total for the Tancarville Canal	6 032 000

The Chamber of Commerce has made two loans to the State besides, viz.:

1st. Law of August 5th, 1874 (interest on the amount at 4½ per cent.)	6 000 000
2d. Law of May 22d, 1888	2 350 000
	8 350 000

The first of these loans was paid in 1887, before due, to the amount of 6 822 425 francs. The second loan is to be paid in six annuities, beginning in 1888.

(*e*) These duties are collected wholly by the Chamber of Commerce of Havre; their tender being for 11 116 000 francs out of the 13 694 000 francs of subsidies furnished for the Port of Havre and the Tancarville Canal.

[2] BORDEAUX—

(*a*) The channel of approach of the Port of Bordeaux has been considered to include all of the river below. It is known that this channel presents a series of shoals where the depth is a function of the normal discharge. The heavy figures refer to the highest of the bars in 1875 (that of Bec d'Ambes). The light figures refer to the highest bar in 1891 (that of Bassens). The large figures refer to the different bars of the river.

(*b*) The bar of Bacalan which forms the down-stream limit is considered as being in the Bordeaux roadstead.

(*c*) These lengths are those of the vertical quays accessible to vessels. For river boats the banks are arranged in inclined ramps, from 20 to 23% for a length of 5 450 m. and with dry walls at 45% for 4 354 m.

(*d*) This includes the expenses for the improvement of the Garonne below Bordeaux and for the Gironde. These expenses have reached the sum of 14 060 521 francs.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*e*) The probable date of completion of the works is indeterminate. It is expected, however, to finish the new vertical quays of the port in 1894.

(*f*) Grant from the Chamber of Commerce, which has besides made several loans to the State, viz.:

	Francs.
Port of Bordeaux:	
1st. Law of May 20th, 1886 (interest, 4 per cent.)	10 000 000
2d. Law of August 5th, 1874 (interest, 4 per cent.)	4 500 000
	14 500 000
Which was repaid in 1881 before due with 18 601 224 francs.	
2d. Law of July 15th, 1885 (payable without interest in 10 years from 1886)	3 500 000
	18 000 000
Maritime Garonne and Gironde:	
Law of August 9th, 1888	24 000 000

Payable without interest in 12 years from 1888.

(*g*) This duty has been collected since August 5th, 1887. It is designed to cover the obligation which the Chamber of Commerce contracted in order to furnish to the State a grant of 10 000 000 francs for the construction of new quays in accordance with the law of August 2d, 1887.

(*h*) This amount is made up as follows:

	Francs.
Law of August 5th, 1874, tax of 0.25 franc	1 094 106
Law of July 15th, 1885, tax of 0.12 franc	1 074 772
Law of August 2d, 1887, tax of 0.60	3 437 748
	5 606 626

3. DUNKIRK—

(*a*) From 1785 to 1845	15 000 000
Law of July 16th, 1845	8 000 000
Decree of July 14th, 1861	15 000 000
	38 000 000

(*b*) This date applies to the works in actual progress and not to the basins of the East, where the work has been provisionally suspended.

(*c*) Grant from the city and from the Chamber of Commerce of Dunkirk.

The City of Dunkirk advanced to the State besides for the works of extension (basin of Freycinet), 31 million francs, payable without interest in 20 annuities, from 1887 to 1906 (law of September 1st, 1884).

(*d*) Grant from the Chamber of Commerce of Dunkirk intended for the reconstruction of the jetty of the East, the cost of which is estimated at 4 900 000 francs.

	Francs.
(*e*) From 1876 to 1881 (tax of 0.10 franc per ton of capacity, law of December 14th, 1875. Restoration works)	466 957
From 1876 to 1882 (tax of 0.30 franc per ton of capacity, law of December 14th, 1875. Works of improvement)	1 293 383
From 1882 to 1884 (tax of 0.40 franc per ton of capacity, law of February 5th, 1882. Works of improvement)	911 221
From October, 1884, to September, 1890 (tax of 0.70 franc per ton of capacity, law of September 1st, 1884. Works of improvement)	4 613 499
From September, 1890, to December, 1892 (tax of 0.54 franc per ton of capacity, law of August 26th, 1890. Works of improvement)	1 661 381
Total receipts from 1876 to 1892	8 946 441

REMARKS ON APPENDIX No. 1—(*Continued*).

4 ROUEN—

(*a*) The water level being lower at neap tide than at spring tide, the figures opposite indicate the depths at low water of minimum neap tide which are the actual minimum depths.

(*b*) These include the expenses incurred and to be incurred for improvement works upon the Seine between Rouen and the sea.

These expenses may be separated as follows:

	Francs.
Prior to 1876	18 097 900
From 1876 to 1891	12 738 644
	80 836 544
Expenses still to be incurred	3 565 728
(*c*) Law of December 14th, 1875, Chamber of Commerce	1 000 000
Law of August 8th, 1879 { Chamber of Commerce	1 200 000
Law of August 8th, 1879 { Department	1 000 000
Law of March 11th, 1882, Chamber of Commerce	3 166 667
Decree of October 1st, 1861, Chamber of Commerce	471 000
	6 837 667

Besides, by virtue of the law of March 11, 1885, the Chamber of Commerce advanced to the State 6 333 333 francs payable at 4% in 20 annuities, from 1887 to 1906.

5 SAINT NAZAIRE—

(*a*) The projected depths are those which will result from dredging the channel across the bar of Charpentiers now in progress and from the works at the new entrance of the port to be constructed in the axis of the basins.

(*b*) Not including the cost of the new entrance (11 800 000 francs) the works for which can be completed in 1899.

(*c*) This grant is made up as follows:

	Francs.
Improvement of the entrance of the port (law of March 28th, 1889). Chamber of Commerce	3 000 000
Deepening of the first basin (decree of January 8th, 1893). Chamber of Commerce	330 000
	3 330 000

Besides, the Department of the Loire Inférieure, in virtue of the law of Jannary 5th, 1875, advanced 10 000 000 francs to the State in order to hasten the completion of the basin of Penhouet; this was paid in 1881 before due, the amount being 10 995 378 francs which included interest at 4 per cent.

(*d*) Tax established by the law of March 28th, 1889. It has been reduced to 0.40 franc for vessels loaded with wood and to 0.30 franc for vessels loaded with coal. The tax established by the law of January 5th, 1875, for the benefit of the department reached 0.53 franc; it was collected to 1881.

(*e*) This includes 879 670 francs collected from 1876 to 1881, in compliance with the law of January 5th, 1875.

6 BOULOGNE—

(*a*) Exterior channel.

(*b*) Channel between the jetties.

(*c*) Exterior pass.

(*d*) Quay of the Traverse where the depth of water will be 5 m. at low tide.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*e*) This amount is made up as follows:

	Francs.
Law of June 17th, 1878, Chamber of Commerce	600 000
Gift from the City of Boulogne	132 896
Law of September 1st, 1884, Chamber of Commerce	2 000 000
Law of October 4th, 1888, Chamber of Commerce	3 200 000
	5 932 896

By virtue of the law of September 1st, 1884, the Chamber of Commerce advanced to the State 4 000 000 francs besides, payable at 4% in 15 yearly payments from 1887 to 1901.

(*f*) For freight, tax of 0.10 to 0.60 franc per ton according to the kind of traffic, the number of shipments and the quantity of freight shipped or received. For passengers, taxes of 0.50, 0.875 or 1.75 francs per passenger embarked or disembarked, according to the class, the destination or the nationality of the passengers (law of October 4th, 1888, and decree of July 9th, 1889).

The tax of 0.10 to 0 60 franc will be reduced to one-fourth or to one-half if the vessel unloads or loads a chartered number of tons not over one-half or three-fourths the tonnage capacity corresponding to its legal capacity (decree of August 6th, 1890).

7 CALAIS—

(*a*) This includes 2.25 m. for the tidal quay where one finds at low tide a depth of 2.50 to 3 m., sufficient for passenger packet boats.

(*b*) This includes 550 m. for the quay of the maritime station and 250 m. for the south quay of the outer harbor.

(*c*) This includes 550 m. for the quay of the maritime station and 445 m. for the south quay of the outer harbor and the new tidal quay where the depth will be 7 m.

(*d*) Gift from the Chamber of Commerce, which, besides, has advanced 12 450 000 francs, 8 450 000 francs of which will be repaid with interest at 4% in 20 annual payments from 1887 to 1906 (law of September 1st, 1884) and 4 000 000 francs without interest in 17 equal instalments (law of December 4th, 1888).

The Chamber of Commerce also advanced 9 023 300 francs for the construction of works under the law of December 14th, 1875; this was repaid in 1881, before due by 9 748 366 francs which included interest at 4 per cent.

8 DIEPPE—

(*a*) The works still to be done consist in the construction of a dry dock and the completion of the terre-pleins.

(*b*)

	Francs.
Gift of the Chamber of Commerce representing different interests	4 960 000
Remaining from the decree of February 21st, 1863	417 777
Gift from the City of Dieppe	45 000
	5 422 777

The Chamber of Commerce has, besides, advanced 4 950 000 francs payable at 4% in 12 annual payments from 1887 to 1898 (law of September 3d, 1884).

9 LA ROCHELLE, PORT PROPER, PORT OF LA PALLICE—

(*a*) From small fisheries only. The codfish from the Grand Banks and from Iceland are included in the goods traffic.

(*b*) Not including the cost of the junction works of the Morans canal with the port which has increased the useful length of the landing stage by 347 m.

(*c*) This includes 300 m. the length of certain parts of the jetties which present a platform 7 m. wide and 210 m. the length of the flying bridges of the outer harbor. These are not, properly speaking, stranding quays. Upon the 300 m. of jetties and upon 100 m. of flying bridges, ships of less than 5-m. draft will float at all times; upon 110 m. of flying bridges, ships of less than 7-m. draft will float at all times.

(*d*) Loan from the city and from the Chamber of Commerce (law of April 2d, 1880).

The City of La Rochelle advanced to the State 3 950 000 francs payable without interest in four payments beginning in 1891 (law of August 14th, 1888).

REMARKS ON APPENDIX No. 1—(*Continued*).

[10] ST. MALO, ST. SERVAN—

(*a*) Loan from the Chamber of Commerce of St. Malo for the completion of the wet dock (decree of April 28th, 1886).

(*b*) The receipt of the duties only began in 1892.

[11] BAYONNE—

(*a*) Loan from the City of Bayonne for improvement works.

The Chamber of Commerce has also advanced to the State 760 000 francs payable without interest in four annual payments beginning in 1890 (law of March 18th, 1889).

[12] ROCHEFORT—

(*a*) Mean depth of the Charente in the commercial harbor.

(*b*) This includes 2 435 441 francs dedicated to the improvement of the maritime Charente.

(*c*) This loan is divided as follows:

	Francs.
Improvement of the maritime Charente	200 000
Dry dock	197 012
3d. Wet dock	1 460 000
Say, for the City of Rochefort	1 857 012
Installations of plant by the Chamber of Commerce—sheds and storehouses	385 000
	2 242 012

(*d*) Tonnage duty for the benefit of the City of Rochefort by decree of May 23d, 1887, and law of July 23d, 1892.

[13] CAEN-OUISTREHAM—

	Francs
(*a*) City of Caen	408 000
Department	371 000
	779 000

[14] HONFLEUR—

(*a*) City of Honfleur	600 000
Department	600 000
Chamber of Commerce	1 648 020
	2 848 020

[15] NANTES—

(*a*) This includes the expenses for the maritime canal of the lower Loire, which amounts to 26 160 francs.

(*b*) Tonnage duty collected by the Chamber of Commerce of Nantes since April 1st, 1889, by virtue of the law of March 28th, 1889.

[16] CHERBOURG—

(*a*) This loan is made up as follows:

	Francs.
Law of February 3d, 1880—Improvement, { City	250 000
Law of February 3d, 1880—Improvement, { Department	250 000
Construction of a rail upon the quay Napoleon—City	13 333
Law of January 19th, 1885—Improvement, Chamber of Commerce	350 000
Construction in the outer harbor of a little port of shelter for fishing boats—Department and City	42 000
Extension of the rail of the quay Napoleon—City	3 900
	909 233

In accordance with the law of January 19th, 1885, the Chamber of Commerce has advanced to the State, besides, 850 000 francs payable at 4% from 1887 to 1901.

(*b*) Duty collected since January 1st, 1881 (decree of September 22d, 1880).

REMARKS ON APPENDIX No. 1—(*Continued*).

17 BREST—

(*a*) By decision of August 8th, 1890, the administration has under consideration a project for the construction of a *slip en travers* designed to replace the dry dock provided by the law of April 5th, 1883. The Chamber of Commerce would contribute 180 000 francs towards the cost and take charge of the operation of this apparatus by the help of a tonnage tax.

18 LES SABLES—

(*a*) Loan from the city for the improvement of the quay of the Remblai.

19 TROUVILLE—

	Francs.
(*a*) Commune of Trouville	180 000
Commune of Deanville	43 000
Department	203 000
Chamber of Commerce	500 000
	926 000

20 TRÉPORT—

(*a*) Law of April 3d, 1880.

Department		500 000
City of Tréport		100 000
Chamber of Commerce of Dieppe		30 000
Chamber of Commerce of Tréport		33 000
M. le Comte de Laris		30 000
		693 000
Decree of April 28th, 1892.		
Department	200 000	
Chamber of Commerce of Dieppe	900 000	
		1 100 000
		1 793 000

21 GRANVILLE—

(*a*) The City of Granville	13 300
The department	26 600
Deepening of the 2d wet dock	
Decree of March 19th, 1883	
The city	42 500
The department	42 500
Dry docks	
	124 900

22 ST. MARTIN DE RUE—

(*a*) The works executed at St. Martin from 1876 to 1891 consist in the improvement of the entrance and the construction of a new entrance lock for the wet dock. The sill of this lock is at the height 0.77 m. above the 0 of the marine charts, while the sill of the old lock was 1.80 m. above. But the channel at the entrance of the port and the bottom of the wet dock are about 0.50 m. above the sill of the new lock; it follows that the projected improvement will not be fully completed until these high bottoms have been removed.

23 BLAYE—

(*a*) The depths given are average depths in the channel.

24 FÉCAMP—

(*a*) This number includes only the fish landed at Fécamp. The vessels fitted out at Fécamp caught, in 1891, 19 548 tons of fish.

(*b*) First cost of works for the port since its establishment.

REMARKS ON APPENDIX No. 1—(*Continued*).

	Francs.
(*c*) Department	500 000
City	150 000
Chamber of Commerce	825 000
	1 475 000

(*d*) Only the Chamber of Commerce of Fécamp profits by this tax.
It was only 0.50 franc per ton of capacity from January 1st, 1881, to May 1st, 1885.

(*e*) The collection was only commenced January 1st, 1891.

25 MARSEILLES—

(*a*) Minima depths of water.

1st. In the channel of the old port ..... 7 m.
2d. In the channel of the Major at the entrance of the Joliette ..... 8 m.
3d. In the channel of the Pinede ..... 16 m.

(*b*) These figures show the development of the useful quays for shipping and receiving goods at the interior of the basins, only, if one adds the quays of the repair basins of the channels and outer harbors, one finds—

In 1876 ..... 12 573 m.
In 1891 ..... 18 118 m.

(*c*) These expenses may be separated as follows:

	Before 1876.	From 1876 to 1891	To Oct. 31st, 1891.
State	48 930 738	27 174 806	76 105 544
City of Marseilles	174 077	.....	174 077
Chamber of Commerce	1 400 000	.....	1 400 000
Compagnie des Docks	12 246 573	5 027 717	17 274 310
Totals	62 751 408	32 202 523	94 953 931

These expenses do not include those for equipment:

By the Chamber of Commerce	50 000	6 025 796	6 075 796
By the Compagnie des Docks	16 511 877	784 381	17 295 658
Totals	16 561 877	6 810 177	23 371 454

(*d*) The Compagnie des Docks has contributed to the works authorized by the decree of July 6th, 1875 (fitting out the quays and exterior dikes) the sum of 1 098 500 francs.

(*e*) In accordance with the law of August 5th, 1874, the Chamber of Commerce of Marseilles advanced to the State 17 483 304 francs for works of improvement of the port under the law of July 8th, 1881, and it was at the same time authorized to receive a tonnage tax of 0.10 franc which was collected until July 1st, 1883, and which amounted to 1 979 193 francs.

26 CETTE—

(*a*) The sea level varies in general from 0.90 to 1 m.; the depth of 7 m. is the minimum measured after the winter storms and before the beginning of the summer dredging. In the autumn the minimum depth is 7.50 m. The acquisition of the new dredging plant will perhaps permit of an improvement in the situation.

(*b*) These figures include the quay for large shipping which has a total length of 5 999 m. and the quay for internal navigation.

(*c*) This includes the cost of the postponed works which will reach the sum of 7 534 363 francs.

REMARKS ON APPENDIX No. 1—(*Continued*).

(*d*) Grants from the Department of l'Herault, from the city and from the Chamber of Commerce, each of which must furnish 225 000 francs to be divided into 15 annual payments of 15 000 francs. The P. L. M. Railroad Company is to furnish a grant of 2 000 000 francs for the Harbor of Tranqueville (postponed works) in exchange for land to be taken from the sea.

(*e*) The law of June 14th, 1878, has conceded to the Chamber of Commerce a tonnage tax which ceased to be collected in 1883.

The law of March 18th, 1889, authorized the Chamber of Commerce to advance 6 400 000 francs to the State for improvement works, payable without interest and to collect a statistical tax of 0.10 franc per ton or per package exported or imported at Cette. This tax has already amounted to 576 901 francs.

27 BOUE—

(*a*) The execution of the most important work is postponed indefinitely.

28 CANNES—

(*a*) The City of Cannes is to furnish a subsidy of 300 000 francs for works of improvement authorized by the decree of July 15th, 1891.

APPENDIX No. 2.

Foreign French Commerce for the Years 1891, 1875, 1859, 1847 and 1827.

Tonnage of loaded vessels—Weight and Value of the Cargoes.

	1891.			1875.			1859.			1847.		1827.	
	Loaded vessels. Capacity in thousands of tons.	Merchandise. Weight in thousands of tons.	Merchandise. Value in millions of francs.	Loaded vessels. Capacity in thousands of tons.	Merchandise. Weight in thousands of tons.	Merchandise. Value in millions of francs.	Loaded vessels. Capacity in thousands of tons.	Merchandise. Weight in thousands of tons. (1)	Merchandise. Value in millions of francs.	Loaded vessels. Capacity in thousands of tons.	Merchandise. Value in millions of francs. (2)	Loaded vessels. Capacity in thousands of tons.	Merchandise. Value in millions of francs. (2)
I. Imports:													
By sea — French vessels	4 587	15 974	1 658	2 544	7 781	1 224	1 628	3 768	683	916	443	398	212
By sea — Foreign vessels — Carrying the flag of the country from which they come	6 070		1 176	3 509		1 050	2 002		681	1 269	399	409	125
By sea — Foreign vessels — Other flags	4 352		1 464	1 736		620	373		78	624	80	67	29
Total imports by sea	15 009	15 974	4 298	7 789	7 781	2 834	4 003	3 768	1 442	2 809	922	874	366
By land	.....	10 748	1 640	.....	7 206	1 568	.....	4 690	707	.....	368	.....	200
Total imports	.....	26 722	5 938	.....	14 987	4 562	.....	8 458	2 149	.....	1 290	.....	566
II. Exports:													
By sea — French vessels	4 462	4 920	1 740	2 336	3 539	1 302	1 473	2 098	889	673	339	393	205
By sea — Foreign vessels — Carrying the flag of the country from which they come	3 720		1 238	2 522		1 377	1 291		1 049	678	398	347	
By sea — Foreign vessels — Other flags	1 945		228	819		528	272		139	146	59	93	
Total exports by sea	10 127	4 920	3 206	5 679	3 539	3 207	3 036	2 098	2 077	1 497	796	833	445
By land	.....	3 952	1 525	.....	2 803	1 600	.....	863	678	.....	253	.....	157
Total exports	.....	8 872	4 731	.....	6 342	4 807	.....	2 961	2 755	.....	1 049	.....	602
III. Imports and exports combined:													
By sea	25 136	20 894	7 504	13 468	11 320	6 101	7 039	5 866	3 519	4 306	1 718	1 707	811
By land	.....	14 700	3 165	.....	10 009	3 168	.....	5 553	1 385	.....	621	.....	357
Total	.....	35 594	10 669	.....	21 329	9 269	.....	11 419	4 904	.....	2 339	.....	1 168

(1) The statistics do not give the weight of merchandise previous to the year 1859.

(2) The separation of the values by flags has been made for the years 1847 and 1827 by applying the percentage of a 10-year average to the total value for each of these years.

APPENDIX No. 3.

French Maritime Commerce with Foreign Countries and the Colonies.

Traffic with countries upon: 1st. European seas and the Mediterranean (Algeria not included). 2d. Seas outside of Europe (colonies not included). 3d. The colonies (including Algeria).

Classified under French and foreign flags for both steam navigation and navigation by sailing vessels for the year 1875.

Foreign Maritime Commerce for the year 1875—Steam Navigation.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria not included).												
1st. French vessels	849 098	10 670	859 768	1%	759 539	105 736	865 275	12%	1 608 637	116 406	1 725 043	6%
2d. Foreign vessels—												
Direct navigation	2 482 758	227 369	2 710 127	8%	1 992 053	866 713	2 858 766	30%	4 474 811	1 094 082	5 568 893	19%
Circuit navigation	307 520	16 242	323 762	5%	123 840	138 544	262 384	52%	431 360	154 786	586 146	26%
Total for foreign vessels	2 790 278	243 611	3 033 889	8%	2 115 893	1 005 257	3 121 150	32%	4 906 171	1 248 868	6 155 039	20%
Grand total	3 639 376	254 281	3 893 657	6%	2 875 432	1 110 993	3 986 425	27%	6 5 4 808	1 365 274	7 880 082	17%
Percentage for French vessels	23%	4%	22%	.....	26%	8%	21%	.....	24%	8%	21%	

APPENDIX No. 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels	269 479	.....	268 479	.....	283 085	100	283 185	.....	552 564	100	552 664	
2d. Foreign vessels—												
Direct navigation.....	49 610	.....	49 610	.....	7 158	470	7 628	6%	56 768	470	57 238	0.8%
Circuit navigation	344 645	.....	343 645	.....	368 779	747	369 526	0.2%	713 424	747	714 171	0.1%
Total for foreign vessels	394 255	.....	394 255	.....	375 937	1 217	377 154	0.3%	770 192	1 217	771 409	0.1%
Grand total	663 734	.....	653 734	.....	659 022	1 317	660 339	0.2%	1 322 756	1 317	1 324 073	
Percentage for French vessels	40%	.....	40%	.....	42%	7%	42%	.....	41%	7%	41%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	1 118 577	10 670	1 129 247	0.9%	1 012 624	105 836	1 148 460	9%	2 161 201	116 506	2 277 707	5%
2d. Foreign vessels--												
Direct navigation	2 532 368	227 369	2 759 737	8%	1 999 211	867 183	2 866 394	30%	4 531 579	1 094 552	5 626 131	19%
Circuit navigation	652 165	16 242	668 407	2%	492 619	139 291	631 910	22%	1 144 784	155 533	1 300 317	11%
Total for foreign vessels	3 184 533	243 611	3 428 144	7%	2 491 830	1 006 474	3 498 304	28%	5 676 363	1 250 085	6 926 448	18%
Total	4 303 110	254 281	4 557 391	5%	3 534 454	1 112 310	4 646 764	23%	7 837 564	1 366 591	9 204 155	14%
Percentage for French vessels	4%	4%	24%	.....	29%	9%	24%	.....	27%	8%	24%	

French Colonies.

Algeria — French vessels	516 616	271	516 887	.....	532 818	33 805	566 723	5%	1 049 534	34 076	1 083 610	3%
Algeria — Foreign vessels	41 936	.....	41 936	.....	5 188	6 327	11 515	55%	47 124	6 327	53 451	11%
Other colonies — French vessels	1 364	.....	1 364	.....	2 188	.....	2 188	.....	3 552	.....	3 552	
Other colonies — Foreign vessels	1 366	.....	1 366	.....	3 997	.....	3 997	.....	5 363	.....	5 363	
Total .. French vessels	517 980	271	518 251	.....	535 106	33 805	568 911	5%	1 053 086	34 076	1 087 162	3%
Total .. Foreign vessels	43 302	.....	43 302	.....	9 185	6 327	15 512	40%	52 487	6 327	58 814	10%
Grand total	561 282	271	561 553	.....	544 291	40 132	584 423	6%	1 105 573	40 403	1 145 976	3%
Percentage for French vessels	92%	100%	92%	.....	98%	84%	97%	.....	95%	84%	94%	

APPENDIX No. 3—(*Continued*).

Navigation by Sailing Vessels.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Cargoes.	Ballast.	Total.	
International Coast Trade (Algeria not included).												
1st. French vessels.....	442 734	102 242	544 976	18%	348 838	273 325	622 163	43%	791 572	375 567	1 167 139	32%
2d. Foreign vessels—												
Direct navigation.....	823 209	104 204	927 413	11%	498 395	564 493	1 062 888	53%	1 321 604	668 697	1 990 301	33%
Circuit navigation.....	647 627	14 516	662 143	2%	202 284	456 559	658 843	69%	849 911	471 075	1 320 986	35%
Total for foreign vessels.	1 470 836	118 720	1 589 556	6%	700 679	1 021 052	1 721 731	59%	2 171 515	1 139 772	3 311 287	34%
Grand total.....	1 913 570	220 962	2 134 532	10%	1 049 517	1 294 377	2 343 894	55%	2 963 087	1 515 339	4 478 426	33%
Percentage for French vessels.....	23%	46%	25%	.....	33%	21%	26%	.....	26%	24%	26%	

To Distant Ports (French Colonies not included).

1st. French vessels.....	242 118	740	242 858	0.3%	221 575	29 713	251 288	11%	463 693	30 453	494 146	6%
2d. Foreign vessels—												
Direct navigation.....	153 677	1 527	155 204	0.9%	24 693	68 031	92 724	73%	178 370	69 558	247 928	28%
Circuit navigation.....	348 561	574	349 135	0.1%	99 916	185 714	285 630	65%	448 477	186 288	634 763	29%
Total for foreign vessels.....	502 238	2 101	504 339	0.4%	124 609	253 745	378 354	67%	626 874	255 846	882 693	28%
Grand total.....	744 356	2 841	747 197	0.3%	346 184	283 458	629 642	45%	1 090 540	286 299	1 376 839	20%
Percentage for French vessels.....	32%	26%	32%	.....	64%	10%	39%	.....	42%	10%	35%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels.....	684 852	102 982	787 834	13%	570 413	303 038	873 451	34%	1 255 265	406 020	1 661 285	24%
2d. Foreign vessels—												
Direct navigation.....	976 886	105 731	1 082 617	9%	523 088	632 524	1 155 612	54%	1 499 974	738 255	2 238 229	32%
Circuit navigation.....	996 188	15 090	1 011 278	1%	302 200	642 273	944 473	69%	1 298 388	657 363	1 955 751	33%
Total for foreign vessels.....	1 973 074	120 821	2 093 895	5%	825 288	1 274 797	2 100 085	60%	2 798 362	1 395 618	4 193 980	33%
Grand total.....	2 657 926	223 803	2 881 729	7%	1 395 701	1 577 835	2 973 536	53%	4 053 627	1 801 638	5 855 265	30%
Percentage for French vessels.....	25%	46%	27%	.....	40%	19%	29%	.....	30%	22%	28%	

APPENDIX No. 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Cargoes.	Ballast.	Total.	
FRENCH COLONIES.												
Algeria..... French vessels.....	41 695	.....	41 695	2%	21 305	6 994	28 299	24%	63 000	6 994	69 994	10%
Algeria..... Foreign vessels....	15 800	400	16 200		6 678	14 601	21 279	68%	22 478	15 001	37 479	40%
Other colonies French vessels.....	121 715	112	121 827	4%	113 156	6 696	119 852	5%	334 871	6 808	241 679	2%
Other colonies Foreign vessels....	28 504	1 417	29 921		8 738	5 563	14 301	38%	37 242	6 980	44 222	15%
Total... French vessels.....	163 410	112	163 522	3%	134 461	13 690	148 151	9%	297 871	13 802	311 673	4%
Total... Foreign vessels.....	44 304	1 817	46 121		15 416	20 164	35 580	56%	59 720	21 987	81 701	26%
Grand total.....	207 714	1 929	209 643	0.9%	147 877	33 854	183 731	18%	357 591	35 783	393 374	9%
Percentage for French vessels.....	78%	5%	78%	.....	89%	40%	80%	.....	83%	38%	79%	

APPENDIX 3—(*Continued*).

Sail and Steam Navigation Combined.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria not included).												
1st. French vessels.....	1 291 832	112 912	1 404 744	8%	1 108 377	379 061	1 487 438	25%	2 400 209	491 973	2 892 182	17%
2d. Foreign vessels—												
Direct navigation.....	3 305 967	331 573	3 637 540	9%	2 490 448	1 431 206	3 921 654	36%	5 796 415	1 762 779	7 559 194	23%
Circuit navigation.....	955 147	30 758	985 905	3%	826 124	595 103	921 227	64%	1 281 271	625 861	1 907 132	32%
Total for foreign vessels.....	4 261 114	362 331	4 623 445	7%	2 816 572	2 026 309	4 842 881	41%	7 077 686	2 388 640	9 466 326	25%
Grand total	5 552 946	475 243	6 028 189	7%	3 924 949	2 405 370	6 330 319	37%	9 477 895	2 880 613	12 358 508	23%
Percentage for French vessels.....	23%	23%	23%	.....	28%	15%	23%	.....	25%	17%	23%	

APPENDIX 3—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels.....	511 597	740	512 337	0.1%	504 660	29 813	534 473	5%	1 016 257	30 553	1 046 810	2%
2d. Foreign vessels—												
Direct navigation.....	203 287	1 527	204 814	0.7%	31 851	68 501	100 352	68%	235 138	70 028	305 166	22%
Circuit navigation.....	693 206	574	693 780	.....	468 695	186 461	655 156	28%	1 161 901	187 035	1 348 935	13%
Total for foreign vessels.....	896 493	2 101	898 594	0.2%	500 546	254 962	755 508	33%	1 397 039	257 063	1 654 102	15%
Grand total.....	1 408 090	2 841	1 410 931	.....	1 005 206	284 775	1 289 981	22%	2 413 296	287 616	2 700 912	10%
Percentage for French vessels.....	36%	23%	36%	.....	50%	10%	41%	.....	42%	10%	38%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	1 803 429	113 652	1 917 081	5%	1 613 037	408 874	2 021 911	20%	3 416 466	522 526	3 938 992	13%
2d. Foreign vessels—												
Direct navigation	3 509 254	333 100	3 842 354	8%	2 522 299	1 499 707	4 022 006	37%	6 031 553	1 832 807	7 864 360	23%
Circuit navigation	1 648 353	31 332	1 679 685	2%	794 819	781 564	1 576 383	49%	2 443 172	812 896	3 256 068	24%
Total for foreign vessels	5 157 607	364 432	6 522 039	6%	3 317 118	2 281 271	5 598 389	40%	8 474 725	2 645 703	11 120 428	23%
Grand total	6 961 036	478 084	7 439 120	6%	4 930 155	2 690 145	7 620 300	35%	11 891 191	3 168 229	15 959 420	21%
Percentage for French vessels	25%	23%	25%	.....	32%	15%	26%	.....	28%	16%	26%	

French Colonies.

Algeria — French vessels	558 311	271	558 582	.....	554 223	40 799	595 022	6%	1 112 534	41 070	1 153 604	3%
Algeria — Foreign vessels	57 736	400	58 136	6%	11 866	20 928	32 794	64%	69 602	21 328	90 930	23%
Other colonies — French vessels	123 079	112	123 191	.....	115 344	6 696	122 040	5%	238 423	6 808	245 231	2%
Other colonies — Foreign vessels	39 870	1 417	31 287	4%	12 735	5 563	18 298	30%	42 605	6 980	49 585	14%
Total. — French vessels	681 390	383	681 773	.....	669 567	47 495	717 062	6%	1 350 987	47 878	1 398 835	3%
Total. — Foreign vessels	87 606	1 817	89 423	2%	24 601	26 491	51 092	51%	112 207	28 308	140 515	20%
Grand total	768 996	2 200	771 196	2%	694 168	73 986	768 154	9%	1 463 164	76 186	1 539 550	4%
Percentage for French vessels	88%	17%	88%	.....	96%	64%	93%	.....	92%	62%	90%	

APPENDIX No. 4.

French Maritime Commerce with Foreign Countries and the Colonies.

Traffic with countries upon: 1st. European seas and the Mediterranean (Algeria not included). 2d. Seas outside of Europe (Colonies not included). 3d. The Colonies (including Algeria and Tunis).

Classified under French and foreign flags for both steam navigation and navigation by sailing vessels for the year 1891.

Navigation by Sailing Vessels.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria and Tunis not included).												
1st. French vessels	158 579	15 582	174 161	8%	134 444	94 250	228 694	41%	293 023	109 832	402 855	27%
2d. Foreign vessels—												
Direct navigation	429 381	75 168	504 549	14%	238 209	619 103	857 312	72%	667 590	694 271	1 361 861	50%
Circuit navigation	339 094	13 985	353 079	4%	173 451	295 122	468 573	62%	512 545	309 107	821 652	37%
Total for foreign vessels	768 475	89 153	357 628	10%	411 660	914 225	1 325 885	68%	1 180 135	1 003 378	2 183 513	45%
Grand total	927 054	104 735	1 031 789	10%	546 104	1 008 475	1 554 579	64%	1 473 158	1 113 210	2 586 368	43%
Percentage for French vessels	17%	14%	16%	.....	24%	9%	14%	.....	19%	9%	15%	

To Distant Ports (French Colonies not included).

1st. French vessels	60 063	.....	60 063	.....	25 014	20 758	45 772	45%	85 077	20 758	105 835	19%
2d. Foreign vessels—												
Direct navigation	151 755	.....	151 755	.....	1 194	26 328	27 552	95%	152 949	26 328	179 277	14%
Circuit navigation	639 887	.....	639 887	.....	101 711	134 930	236 641	57%	741 598	134 930	876 528	15%
Total for foreign vessels	791 642	.....	791 642	.....	102 905	161 258	264 163	61%	894 547	161 258	1 055 805	15%
Total	851 705	.....	851 705	.....	127 919	182 016	309 935	58%	979 624	182 016	1 161 640	15%
Percentage for French vessels	7%	.....	7%	.....	19%	11%	14%	.....	8%	11%	9%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	218 642	15 582	234 224	6%	159 458	115 008	274 466	41%	387 100	130 590	503 690	25%
2d. Foreign vessels—												
Direct navigation	581 136	75 168	656 304	11%	239 403	645 431	884 834	72%	820 539	720 599	1 541 138	46%
Circuit navigation	978 981	13 985	992 966	1%	275 162	430 052	705 214	60%	1 254 143	444 037	1 698 180	26%
Total for foreign vessels	1 560 117	89 153	1 649 270	5%	514 565	1 075 483	1 590 048	67%	2 074 682	1 164 636	3 239 318	35%
Grand total	1 778 759	104 735	1 883 494	5%	674 023	1 090 491	1 864 514	63%	2 452 782	1 295 226	3 748 008	34%
Percentage for French vessels	12%	14%	12%	.....	23%	9%	14%	.....	15%	10%	13%	

APPENDIX No. 4—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
French Colonies.												
Algeria and Tunis { French vessels.	7 234	2 951	10 185	29%	4 643	10 265	14 908	68%	11 877	13 216	25 093	52%
Algeria and Tunis { Foreign vessels.	8 935	.....	8 935	.....	10 102	4 333	14 435	30%	19 037	4 333	23 370	18%
Other Colonies.... { French vessels.	53 955	.....	53 955	.....	58 913	2 243	61 156	3%	112 868	2 243	115 111	1%
Other Colonies.... { Foreign vessels.	53 858	.....	33 858	.....	20 253	2 103	22 356	9%	54 111	2 103	56 214	3%
Total..... { French vessels.	61 189	2 951	64 140	4%	63 556	12 508	76 064	16%	124 745	15 459	140 204	11%
Total..... { Foreign vessels.	42 793	.....	42 793	.....	30 355	6 436	36 791	17%	73 148	6 436	79 584	8%
Grand total.....	103 982	2 951	106 933	2%	93 911	18 944	112 855	16%	197 893	2 895	219 788	9%
Percentage for French vessels.....	58%	100%	60%	.....	67%	66%	67%	.....	63%	71%	63%	

APPENDIX No. 4—(*Continued*).

Steam Navigation.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria and Tunis not included).												
1st. French vessels.....	1 902 761	87 033	1 989 794	4%	1 835 280	368 779	2 204 059	16%	3 738 041	455 812	4 193 853	10%
2d. Foreign vessels—												
Direct navigation.....	4 830 127	282 971	5 113 098	5%	3 393 105	2 476 754	5 869 859	42%	8 223 232	2 759 725	10 982 957	25%
Circuit navigation.....	1 903 742	63 593	1 967 335	3%	943 943	1 644 415	2 588 358	63%	2 847 685	1 708 008	4 555 693	37%
Total for foreign vessels.....	6 733 869	346 564	7 080 433	4%	4 337 048	4 121 169	8 458 217	48%	11 070 917	4 467 733	15 538 650	28%
Grand total.....	8 636 630	433 597	9 070 227	4%	6 172 328	4 489 948	10 662 276	42%	14 808 958	4 923 545	19 732 503	24%
Percentage for French vessels.....	22%	20%	21%	.....	29%	8%	20%	.....	25%	9%	21%	

APPENDIX No. 4—(*Continued*).

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded	In ballast	Total.		Loaded.	In ballast	Total.		Loaded.	In ballast.	Total.	
To Distant Ports (French Colonies not included).												
1st. French vessels.....	862 456	4 262	866 718	0.4%	869 561	30 200	899 761	3%	1 732 017	34 462	1 766 479	2%
2d. Foreign vessels—												
Direct navigation.....	658 980	.....	658 980	.....	87 024	42 408	129 432	32%	746 004	42 408	788 412	5%
Circuit navigation.....	1 287 674	38 024	1 325 698	2%	634 286	47 926	682 212	7%	1 921 960	85 950	2 007 910	4%
Total for foreign vessels.....	1 946 654	38 024	1 984 678	1%	721 310	90 334	811 644	11%	2 667 964	128 358	2 796 322	4%
Grand total.....	2 809 110	42 286	2 851 396	1%	1 590 871	120 534	1 711 405	7%	4 399 981	162 820	4 562 801	3%
Percentage for French vessels.....	30%	10%	30%	.....	54%	25%	52%	.....	39%	21%	38%	.....

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included).

1st. French vessels	2 765 217	91 295	2 856 512	3%	2 704 841	398 979	3 103 820	12%	5 470 058	490 274	5 960 332	8%
2d. Foreign vessels—												
Direct navigation	5 489 107	282 971	5 772 078	4%	3 480 129	2 519 162	5 999 291	41%	8 969 236	2 802 133	11 771 369	23%
Circuit navigation	3 191 416	101 617	3 293 033	3%	1 578 229	1 692 341	3 270 570	51%	4 769 645	1 793 958	6 563 603	27%
Total for foreign vessels	8 680 523	384 588	9 065 111	4%	5 058 358	4 211 503	9 269 861	45%	13 738 881	4 596 091	18 334 972	25%
Grand total	11 445 740	475 883	11 921 623	4%	7 763 199	4 610 482	12 373 681	37%	19 208 939	5 086 365	24 295 304	20%
Percentage for French vessels	24%	19%	23%	.....	34%	8%	25%	.....	28%	9%	24%	

French Colonies.

Algeria and Tunis — French vessels	1 352 264	2 889	1 335 153	0.2%	1 320 127	9 442	1 329 569	0.7%	2 672 391	12 331	2 684 722	0.4%
Algeria and Tunis — Foreign vessels	79 244	1 341	80 585	1%	43 678	43 644	87 322	49%	122 922	44 985	167 907	26%
Other colonies — French vessels	126 004	4 154	130 158	3%	150 225	1 186	151 411	0.7%	276 229	5 340	281 569	2%
Other colonies — Foreign vessels	59 030	.....	59 030	.....	17 874	.....	17 874	.....	76 904	.....	76 904	.....
Total — French vessels	1 478 268	7 043	1 485 311	0.4%	1 470 352	10 628	1 480 980	0.7%	2 948 620	17 671	2 966 291	0.6%
Total — Foreign vessels	138 274	1 341	139 615	0.9%	61 552	43 644	105 196	41%	199 826	44 985	244 811	18%
Grand total	1 616 542	8 384	1 624 926	0.5%	1 531 904	54 272	1 586 176	3%	3 148 446	62 656	3 211 102	2%
Percentage for French vessels	91%	84%	91%	.....	96%	19%	93%	.....	93%	28%	92%	

APPENDIX 4—(*Continued*).

Foreign Maritime Commerce for the Year 1891.—Sail and Steam Combined.

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
International Coast Trade (Algeria and Tunis not included).												
1st. French vessels.....	261 340	102 615	2 163 955	4%	1 969 724	463 029	2 432 753	19%	4 031 064	565 644	4 596 708	12%
2d. Foreign vessels—												
Direct navigation.....	5 259 508	358 139	5 617 647	6%	3 631 314	3 095 857	6 727 171	46%	8 890 822	3 453 996	12 344 818	27%
Circuit navigation.....	2 242 836	77 578	2 320 414	3%	1 117 394	1 939 537	3 056 931	63%	3 360 230	2 017 115	5 377 345	37%
Total for foreign vessels	7 502 344	435 717	7 938 061	5%	4 748 708	5 035 394	9 784 102	51%	12 251 052	5 471 111	17 722 163	30%
Grand total.....	9 563 684	538 332	10 102 016	5%	6 718 432	5 498 423	12 216 855	44%	16 282 116	6 036 755	22 318 871	27%
Percentage for French vessels.....	22%	19%	21%	.....	29%	8%	19%	.....	24%	9%	20%	

To Distant Ports (French Colonies not included).

1st. French vessels.....	922 519	4 262	926 781	0.4%	894 575	50 958	945 533	5%	1 817 094	55 220	1 872 314	3%
2d. Foreign vessels—												
Direct navigation.....	810 735	.....	810 735	.....	88 218	68 736	156 954	44%	898 953	68 736	967 689	7%
Circuit navigation.....	1 927 561	38 024	1 965 585	2%	735 997	182 856	918 853	19%	2 663 558	220 880	2 884 438	7%
Total for foreign vessels.....	2 738 296	38 024	2 776 320	1%	824 215	251 592	1 075 807	23%	3 562 511	289 616	3 852 127	7%
Grand total.....	3 660 815	42 286	3 703 101	1%	1 718 790	302 550	2 021 340	.....	5 379 605	344 836	5 724 441	6%
Percentage for French vessels.....	27%	10%	25%	.....	52%	16%	46%	.....	33%	15%	32%	

RECAPITULATION.

International Coast Trade and to Distant Ports (French Colonies not included.)

1st. French vessels.....	2 983 859	106 877	3 090 736	3%	2 864 299	513 987	3 378 286	15%	5 848 158	620 864	6 469 022	9%
2d. Foreign vessels—												
Direct navigation.....	6 070 243	358 139	6 428 382	5%	3 719 532	3 164 593	6 884 125	45%	9 789 775	3 522 732	13 312 507	26%
Circuit navigation.....	4 170 397	115 602	4 285 999	2%	1 853 391	2 122 393	3 957 784	53%	6 023 788	3 237 995	8 261 783	27%
Total for foreign vessels.....	10 240 640	473 741	10 714 381	4%	5 572 923	5 286 986	10 859 909	48%	15 813 563	5 760 727	21 574 290	26%
Grand total.....	13 224 499	580 618	13 805 117	4%	8 437 222	5 800 973	14 238 195	40%	21 661 721	6 381 591	28 043 312	22%
Percentage for French vessels.....	22%	18%	22%	.....	33%	8%	23%	.....	26%	9%	23%	

APPENDIX 4—(*Continued.*)

	Inbound.			Proportion in ballast.	Outbound.			Proportion in ballast.	Inbound and outbound together.			Proportion in ballast.
	Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.		Loaded.	In ballast.	Total.	
French Colonies.												
Algeria and Tunis. French vessels.	1 359 498	5 840	1 365 338	0.3%	1 324 770	19 707	1 344 477	1%	2 684 268	55 547	2 709 815	0.8%
Algeria and Tunis. Foreign vessels.	88 179	1 341	89 520	1%	53 780	47 977	101 757	47%	141 958	49 318	191 277	25%
Other colonies ... French vessels.	179 958	4 154	184 113	2%	209 138	3 429	212 567	1%	389 097	7 583	396 680	1%
Other colonies ... Foreign vessels.	92 888	.....	92 888	.....	38 127	2 103	40 230	5%	131 015	2 103	133 118	1%
Total..... French vessels...	1 539 457	9 994	1 549 451	0.6%	1 533 908	23 136	1 557 044	1%	3 073 365	33 130	3 106 495	1%
Total..... Foreign vessels..	181 067	1 341	182 408	0.7%	91 907	50 080	141 987	35%	272 974	51 421	324 395	15%
Grand total.....	1 720 524	11 335	1 731 859	0.6%	1 625 815	73 216	1 699 031	4%	3 346 339	84 551	3 430 890	2%
Percentage for French vessels.....	89%	88%	89%	.....	94%	31%	91%	.....	91%	39%	90%	

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

605.

(Vol. XXIX.—July, 1893.)

INLAND TRANSPORTATION.

By Captain F. A. MAHAN, Corps of Engineers, U. S. A.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Transportation is about the most important question entering into the exchange of products from different parts of the world. Where transportation exists free and untrammeled, there the exchange of products takes place readily, and this exchange, which is known as commerce, is increased or diminished almost in exact proportion to the facility with which the articles to be exchanged can be transferred from one point to another.

Transportation means simply a carrying across; that is to say, across some space which lies between the point of production and the point of consumption. Modes of carrying vary in different parts of the world, and civilization might almost be expressed in terms of ease of transfer. In savage countries we find transportation, even for long

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

distances, carried on by means of porters; from this we rise through many gradations of pack and draft animals, of vehicles more or less primitive and cumbersome, of vessels propelled by poles, by oars or by sails, and so on, until is reached the highest development of carriage by land or by sea, with steam as the present best motor. But who shall forecast the future, who shall say that development will not continue, or who shall tell what the coming years may bring forth?

It is proposed in this paper to consider the two means of transportation most used in the United States, and to make, if possible, some comparison between them. These means are rail and water. There is little use made of other sorts except within short distances of certain centers, and as the conditions vary greatly from center to center, there seems to be no way of comparing results.

There must be some point from which to start in making comparisons between rail and water transportation. The point which naturally suggests itself is the consideration of the articles which are mostly carried in common by each highway. The investigation must also have some limits assigned so as to have somewhat assimilated conditions. For example, it would be folly to attempt comparison between a railway joining two points between which water communication cannot be had, and a water-way joining two points between which rail communication cannot be had. As it is more easy to dispose of the limits to which this paper is to be confined than to consider the articles carried on both highways, they will be considered first.

If the United States be studied with care, it will be found that the greatest amount of population and of commercial activity lies in an east and west belt containing the New England and Middle States and those of the Western States lying between the Ohio and Missouri rivers and the Great Lakes. Within these limits are found the great cities of New York, Chicago and Philadelphia, together with those of less degree, such as Portland, Me., Boston, Baltimore, Pittsburgh, Buffalo, Cincinnati, Cleveland, Detroit, Duluth, St. Louis and many others, to mention all of which would lead far beyond what is required in an article so general in its character as this.

This belt contains the most important transportation routes of the country. From New York leads west the route by the Hudson River, the Erie Canal and the Great Lakes. From the same point lead the great railroad routes—the Pennsylvania, the New York Central

and Hudson River, the Erie, the Delaware, Lackawanna and Western, the Lehigh Valley, the Baltimore and Ohio, the New York, West Shore and Buffalo. From Pittsburgh starts the Ohio River, which joins the combined Upper Mississippi and Missouri at Cairo. These three streams form that great river, the Mississippi, one of the main highways of commerce of the country.

The boundaries of the field over which it is proposed to travel being fixed, it may be well to see on what ground the lines of transportation mentioned above may be placed, so as to form some sort of comparison between them; in other words, are there any articles of merchandise carried by both to such an extent as to give the means of comparing one with the other? It will therefore be well to consider what is carried along these routes, and to find whence it comes and whither it goes.

The articles which seek the water routes are generally of the bulky sort, in the delivery of which time enters but little, but which must come regularly, so that the supply may be maintained continuously. Ore, for example, or coal or grain is eminently suited to water carriage. Neither deteriorates appreciably by reason of slow transportation. If a given number of tons per day be required, it is only the average which need be maintained, as it matters little whether the per diem average be delivered daily, or twice the amount on alternate days, or thrice the amount twice a week. This class of goods has been found, by universal experience, to be best adapted to water transportation. M. Fleury says, in speaking of the parts played by water and railways in France: "The only elements of traffic which can be divided between the water-way and the railway are raw materials and agricultural products, which, as a rule, can only stand a low rate of carriage, and which go frequently in large quantities and over long distances." The same is true of this country. Grain and timber follow the lakes and the Erie Canal. Ore and coal follow the lakes so far as possible. Coal follows the Ohio and Mississippi.

Where, then, are the sources of supply? Where are the points of distribution and concentration? What are the routes followed? How does the cost of transportation compare by rail and by water?

The grain supply comes largely from the western and north-western part of the field mentioned. The supply from the northwest is concentrated at Duluth, at the extreme end of Lake Superior; that

from the western part comes in at Chicago. Iron ore comes from the south shore of Lake Superior. Anthracite coal comes from the north-eastern part of Pennsylvania, and bituminous coal from western Pennsylvania and West Virginia. The concentration of grain at Duluth and Chicago is by rail. It is moved from Chicago mainly by way of the lakes to Buffalo, whence it goes on its eastward journey to New York by canal and rail. The rail shipments from Duluth direct to eastern ports become important. Large quantities of grain go by the lakes to Buffalo, as is the case with Duluth. After leaving the Straits of Mackinac, the route followed by the Chicago grain is the same as that followed by the Duluth grain after leaving the mouth of the St. Mary's River. In each case the transportation is now by large iron or steel steamers, carrying from 60 000 to 120 000 bushels at a trip. The iron ore comes from sundry ports on the south shore of Lake Superior, some in Michigan, some in Wisconsin, and others again in Minnesota. It is carried in large vessels to Cleveland and other points on Lake Erie, and thence by rail to the furnaces at Pittsburgh and elsewhere.

Anthracite coal is carried by rail from north-eastern Pennsylvania mainly to Buffalo. At this place it is loaded into the vessels which carry it to many of the lake ports—Chicago, Detroit, Duluth, and others. The bituminous coal of western Pennsylvania and some from West Virginia comes down the Monongahela in boats, barges or flats, two or three at a time, to Pittsburgh, where the larger tows are made up to go down the Ohio River.. The great tows for the lower Mississippi are prepared at Louisville.

Bituminous coal is also carried from western Pennsylvania to Erie and other lake ports near at hand, and thence it goes by water to the port nearest to its destination.

In the transportation of any sort of materials, the item of cost is the one which occupies the most important place. The question, so far as the cost of moving grain from Chicago to New York is concerned, has been carefully studied. This transportation presents three features: 1st, all water transportation, that is to say, by the lakes to Buffalo and thence to New York by way of the Erie Canal and Hudson River; 2d, all rail from Chicago to New York; 3d, water to Buffalo and rail thence to New York. The average freight rates for a bushel of wheat from Chicago to New York, for each year from 1868 to 1891, is

given in the following table, taken from the last annual report of the New York Produce Exchange.

Year.	Average Rates per Bushel.			Year.	Average Rates Per Bushel.		
	By Lake and Canal.	By All Rail.	By Lake and Rail.		By Lake and Canal.	By All Rail.	By Lake and Rail.
	Cents.	Cents.	Cents.		Cents.	Cents.	Cents.
1868.....	22.79	42.6	29.0	1880.....	12.27	19.9	15.7
1869.....	25.12	35.1	25.0	1881.....	8.19	14.4	10.4
1870.....	17.10	33.3	22.0	1882.....	7.89	14.6	10.9
1871.....	20.24	31.0	25.0	1883.....	8.37	16.5	11.5
1872.....	24.47	33.5	28.0	1884.....	6.31	13.12	9.55
1873.....	19.19	33 2	26.9	1885.....	5.87	14.00	9.02
1874.....	14.10	28.7	16.9	1886.....	8.71	16.50	12.00
1875.....	11.43	24.1	14.6	1887.....	8.51	15.74	12.00
1876.....	9.58	16.5	11.8	1888.....	5.93	14.50	11.00
1877.....	11.24	20.3	15.8	1889.....	6.89	15.00	8.70
1878.....	9.15	17.7	11.4	1890.....	5.85	14.31	8.50
1879.....	11.60	17.3	13.3	1891.....	5.96	15.00	8.53

During the year 1891 there was received at New York 124 844 643 bushels of grain by rail. In this quantity are included flour and meal. Let it be assumed that all this grain had been taken to Buffalo or Erie by lake, and from these ports sent to New York by rail. Had it all gone to Buffalo and thence been carried by canal and river, the saving in the cost of transportation would have been $2\frac{57}{100}$ cents on each bushel, giving a total saving of $3 208 500, an item worth considering.

On the Ohio River is found the chance of comparing directly the cost of carrying coal by river with the cost of carrying it by rail. The Pittsburgh Coal Exchange gives the following rates per ton to the various points mentioned.

	By rail.	By river.	Saving by river.
Wheeling, W. Va.....	$0.70	$0.08	$0.62
Parkersburg, W. Va.....	1.25	0.14	1.11
Cincinnati, O.....	1.70	0.46	1.24
Louisville, Ky.....	2.45	0.53	1.92
St. Louis, Mo.....	2.50	1.45	1.05

The cost of the river transportation includes the cost of returning the empty packages to Pittsburgh. These packages are not of the sort to be utilized for return freight, being entirely open and built for no other purpose than that of carrying coal.

The following table shows the effect of competing river routes on railway freight rates. The figures contained therein were given by the Louisville, Ky., Board of Trade. They are suggestive of what may be expected whenever the use of water-ways is abandoned. The rates given are those for freight carried by rail to the points mentioned. It will be noticed that New Orleans is twice as far from Louisville as either Aberdeen, Winona or Grenada, yet the rate to New Orleans is much less than to any of the other points. Why is this? Simply because there is a water route by way of the Ohio and Mississippi rivers from Louisville to New Orleans.

From Louisville, Ky., to—	Rates in Cents per 100 lbs.									
	Distance.	Class.						Bagging and Ties.	Packing House Products.	Flour in Sacks.
	Miles.	1	2	3	4	5	6	A	B	C
New Orleans, La.....	811	90	75	65	50	40	35	25	25	25
Jackson, Miss.....	565	114	94	81	68	56	49	41½	43	40
Aberdeen, Miss.....about	400	114	94	73	62	51	46	38	40	32½
Winona, Miss.....	408	119	97	80	66	54	47	43	46	37
Grenada, Miss.....	395	118	97	80	65	54	47	43	45	40

From Louisville, Ky., to—	Distance.	Grain.	Beer in Wood.	Liquors in Wood.	Flour in Barrels. Per Barrel.	Special Iron.	
	Miles.	D	E	H	F	L. C. L.	C. L.
New Orleans, La.....	811	20	28	25	45	25	18
Jackson, Miss.....	565	32	53	55	78	32	26½
Aberdeen, Miss....about	400	26	37	42	57	31	29
Winona, Miss.....	408	31	48	48	66	36	29
Grenada, Miss.....	395	33	48	54	70	42	36

Special iron list includes nails, bolts, rivets, spikes, fence wire, roofing iron, bar, rod, sheet and band iron, horse and mule shoes, plow molds, plow points, etc.

Classes 1, 2, 3, 4, 5 and 6 include different classes of merchandise, which is classified according to value, weight, liability to damage, etc.

The distance to New Orleans, the point farthest away, is 2.053 times that to Grenada, the nearest point; yet the cost of transportation to

the former is the following per cent. of transportation to the latter, according to the classes in the table.

Class 1	76 per cent.	Class A	58 per cent.
" 2	77 "	" B	55 "
" 3	81 "	" C	60 "
" 4	77 "	" D	60 "
" 5	74 "	" E	58 "
" 6	74 "	" H	46 "
		" F	64 "
		L. C. L	60 "
		C. L	50 "

If, therefore, Grenada had the advantage of water transportation it might have rail freight rates of about one-third of what they are at present.

These two cases, of coal from Pittsburgh and general merchandise from Louisville, show the great advantages to be gained by the competition of water routes by river. They are a repetition of what was found to be the case in the carriage of grain from the West to the East. But, it may be argued, these data are for long distances and are not of value in determining rates when the distances are less. To answer this the writer quotes from Professor James' "The Canal and the Railway":

"The Guthrie Ice Company was engaged for several years in shipping ice from Willow Springs to Chicago by canal—14 miles—and from Summit to Chicago by rail—9 miles. The cost per railroad was 50 cents per ton; by canal, 18 cents, the toll being $5 on each boat carrying 125 tons of ice. The rate per ton-mile on the railroad was 5.55 cents, and on the canal 1.29. The boats were empty one way, and the load had to be moved against a current of 1½ miles per hour in a contracted channel having a cross-section of only about three times the area of that presented by the loaded boat.

"The Bodenschatz and Earnshaw Company of Chicago gave the rates at the same date—October, 1886—per cord of stone from their quarries in Lemont to the city as follows: By rail, $4.50; by canal, $1.95. The Excelsior Stone Company gave the rate as $3.90 and $1.73, respectively."

The water-ways of France and Germany also show economy of transportation when heavy bulky materials are to be carried. The more the question is studied, the more desirable the use of water-ways becomes. It is evident by the great attention which many nations are

bestowing on their navigable highways that there is something real, something tangible, in the economic results to be obtained by water carriage. What some of these economic results may be in the United States, with properly constructed and well-organized water routes, is dimly foreshadowed in what has been already briefly given.

The traffic carried on the lakes in the way of freight is enormous. During the year 1890 the amount of freight transported was 2 003 047 tons to and from foreign ports, and 28 295 959 tons between domestic ports. This domestic trade may be classified as follows:

	Tons.		Tons.
Wheat	807 906	Salt	280 187
Corn	1 769 138	Cement	98 937
Oats	348 216	Stone	323 890
Barley	141 197	Lumber	5 843 421
Rye	42 609	Shingles	134 461
Flaxseed	79 086	Lath	56 660
Flour	922 056	Miscellaneous lumber products	835 118
Mill stuff	161 138	Miscellaneous freight	1 414 750
Coal	5 735 299		
Iron ore	9 132 761		
Pig iron	128 145	Total	28 295 959
Copper	40 894		

All freight traffic between ports on Lakes Erie and Ontario and ports on Lakes Huron, Michigan and Superior must pass through the Detroit River. The net freight tonnage carried on this highway in 1890 was 21 888 472 tons. The vessel tonnage, entrances and clearances in the foreign trade at London in the same year was 13 480 769; and at Liverpool for the same year it was 10 941 800, or for the two, 24 422 569 tons. This total is less by 3 873 390 tons than the domestic lake tonnage of the United States, and greater than the freight passing Detroit by only 2 534 097 tons.

The actual freight passing through the Sault Ste. Marie Canal during each of the last three years was—

9 041 213 tons in 1890
8 888 759 " 1891
11 214 333 " 1892

During the seven months of navigation, May to November, inclusive, in 1891, the amount of freight taken eastward from Chicago was

4 265 934 tons, as stated by the report of the Chicago Board of Trade. Of this amount 2 705 084 tons went by lake, and 1 560 850 tons went by the following railroads: Grand Trunk, Michigan Central, Lake Shore, Pittsburgh, Fort Wayne and Chicago, Pan Handle, Erie, Baltimore and Ohio, Wabash, and Nickel Plate.

As a matter of curiosity it may be interesting to see what would be required in the way of rolling stock if the attempt were made to carry by rail all the domestic lake traffic of the United States. The most powerful freight locomotive, Class "R," used on the Pennsylvania railroad, running at 15 miles per hour on a level and straight track, can exert a pull of 15 300 lbs. This at 3 lbs. per ton-weight of train would draw a train-weight of 5 100 tons under favorable conditions. If the train were made up of heavily loaded cars (*i. e.*, 41 tons each total), there would be 124 vehicles. Taking the average live weight at 25 tons to the car, there would be required 1 131 835 cars, or 9 128 trains of 124 cars each. Allowing for wet tracks, for curves and grades and for other unfavorable conditions, the theoretical number of cars may be reduced to 41 per train, which would increase the number of trains to 27 384, giving 117 trains per day for the 234 days of navigation.

Still, with all the advantages offered by water routes, the tendency of freight is to be absorbed more and more by the railways, except where natural lines of water communication exist of such dimensions, and contain such volumes of water, as to allow the running of vessels of large size. Such water-ways are the Great Lakes, the Mississippi and Ohio Rivers, the Hudson River and various bays and sounds along the coasts. Where these are found, the railways cannot hope to compete for the carriage of certain lines of freight. But the improvements which are constantly made in railway practice and construction have made the iron roads formidable competitors for canals as handled in this country.

The best-known canal route, the Erie, is losing ground steadily at the present time, and the causes which are bringing about this state of affairs are in operation to an even greater extent in other parts of the country. There are also special local causes which have their influence on particular lines, but they do not enter into the general conditions.

First among the causes of the decadence of canals may be placed the entire misapprehension of the probabilities and possibilities of railways. These later lines of transportation came into being before the

canals of the United States were fairly in working order. When it is considered that but little more than 12 years had passed from the date of the opening of the Erie Canal to that of the introduction of railways, it may easily be seen that the water-way had had no opportunity of showing its capabilities when the new highway appeared. The people of this country were carried away by the ideas which rose before them. They saw the speed with which vehicles could be moved over the new roads, and there is little cause for wonder that their feelings should have overpowered their judgment. Such great and marvelous things were expected from, and predicted of, the railways, that the cause of the canals was abandoned before it was known what they could do. The quickness of the railway appealed to the imagination, and visions of what have since been found to be impossibilities began to appear.

One marked difference exists between the railway and the canal. The former owes its life to private enterprise, the latter owes it to the State. The desire for gain is necessarily the mental condition of capital. Improvement of tools is the natural result of competition. Competition between lines cannot exist when one hand controls both lines. It does exist where lines are under different managements. The wish for the greatest returns from the capital invested leads to improved means for obtaining results. The best brains turned towards capital as their work was most appreciated there. Government officials in important positions, whether under the State or under the general Government, are found to be notoriously underpaid when their responsibilities are compared with those resting on the shoulders of men occupying corresponding positions under private corporations. Capital is alive to its interests, the State is not. Private business is arranged on business principles, State affairs are not. Hence it is that during the past 50 years everything connected with railways has undergone great improvements; whereas, the water-ways have been allowed to stand still when they have not been permitted to fall into ruin. During these years, railways have been built in all sorts of places, under all kinds of conditions ; experiments beyond number have been tried on everything which enters into the construction or management of railways. The results of trials, of tests, of experiments, have been collated, compared and studied carefully, and a regular and systematic practice has been developed. Conventions of railway officials from

all parts of the country are held from time to time, to consider and discuss every conceivable problem known to railway practice. Engineers take up questions of construction; master mechanics talk over and read papers on the various problems presented in the building and maintenance of rolling stock; superintendents give their experiences in the maintenance of way and handling of the lines; passenger and freight agents investigate the many ways in which business can be extended, by making lines better known, by offering advantageous rates, by insuring better connections, by expediting service and by such other methods as may be dictated by experience.

What, then, is seen as the result of so much intelligent toil? Compare the railway of to-day with its predecessor of 40 years ago, and what are the points which force themselves at once on the attention? 1st. The great improvement in the road itself; better grades; easier curves; careful ballasting; stronger bridges; heavier and steel rails with almost perfect joints between them. 2d. Increased capacity of the rolling stock; heavier locomotives with improved combustion; larger and stronger cars; better coupling; automatic brakes. 3d. System gradually introduced into management; absorption of many lines into a continuous system under uniform control; methods of soliciting and obtaining business; safety in the movement of trains; improvements at terminal points for facilitating the handling of freight and the movements of passengers.

Such, in very broad strokes, are the principal changes which have taken place. But what an expenditure of brain-power has been required to bring them about! And, having studied all these changes, what is the final result obtained? It may be expressed in one word—economy. Economy of time, and, hence, of money; because, as our proverb has it, "time is money." Economy in direct expenses, and, hence, reduction in the cost of service, as seen by the difference in the cost of carrying grain from Chicago to New York, which was, in 1868, 42.6 cents a bushel, while in 1891 it was only 15 cents, a reduction of 65 per cent.

How do these improvements manifest themselves? A rail is a beam resting on several points of support. The heavier rail bears the greater load. The durability of the steel rail is much more than that of the iron rail, while its present cost scarcely varies from that of the latter. The lighter grade gives a greater load to the same locomotive.

The easier curve reduces friction. Stronger bridges must go with stiffer rails. Careful ballasting and nearly perfect joints cause smoothness of running, and reduce wear and tear on the rolling stock by doing away with the shocks caused by inequalities in the surface of the rails. The heavier locomotive draws the heavier train. Improved methods of combustion evaporate more water, and hence obtain more work from a given weight of fuel. Larger and stronger cars carry a greater live load for a given dead load; therefore, a greater quantity of useful work for the same effort put forth. Better couplings prevent accidents and save time. Automatic brakes diminish expenses by putting the train under better and easier control, and save hands which are needed without them. System saves time and expense by enabling the same number of men to do a greater amount of work. Consolidation or absorption of many lines into one whole brings uniformity of practice, more prompt dispatch of business, and gets rid of many officials. Systematic soliciting of business brings roads into prominence and allows the shipper to know without trouble what points he can reach and how to make his shipments with the least inconvenience and greatest advantage to himself. Improved terminal facilities allow of much larger masses being handled in a given space of time. There is room for work, and confusion is removed.

These are but few of the causes which have led to the great success of railways and to their taking so commanding a position in the workings of the community. The causes are of importance in this article in order to show what has been done for the railways and what has been left undone on the minor water-ways. On those of greater importance, such as the Great Lakes and some of the more traveled rivers, many improvements have been made; but the canals are where they were 25 years ago, years during which the railways have gone ahead with their greatest strides.

Let us see if any parallel can be made between the improvements made on the railways and those which are required for canals. The prism of the canal corresponds with the roadbed of the railway. The strength of the rail finds its counterpart in the area of the cross-section of the prism. The durability of the rail is represented in a certain way by the firmness of the banks of the canal. Lighter grades are repeated in more convenient means for overcoming the step from one level to the next. Curves, ballasting and joints have no counter-

part on the water-way. Increased power in the locomotive is comparable with better means of locomotion in the canal. Improvement in combustion can be applied here as well as on the railway. Larger and stronger cars are comparable with larger and stronger boats.

In addition to these points of similarity there are others which apply alone to canals. For example: the question of rainfall in the matter of the water supply for canals is one of the highest importance, but where is it studied systematically? What experiments have been made on the traction of boats, to determine whether their present shape is that which adapts itself best to economy of the power needed for locomotion, or to learn whether improvements can be made, and, if so, what they are? One trouble with canals is the slow rate of speed which boats must hold so that the waves made by them shall do no harm to the banks; but what is done in the way of studies to determine the best mode of protection so that a higher rate of speed can be allowed without injury to the banks? The passage of a boat from one level to the next is always attended with a great loss of time. With the ordinary lock there are three phases of this operation: 1st, the boat must enter the lock; 2d, the lock must be emptied or filled so that the boat can be lowered or raised; 3d, the boat must pass out of the lock. What can be done to reduce the time required for any or all of these operations? When these different phases have to be repeated several times, as is the case with a flight of locks, the loss of time is something of great moment. If there be seven locks and it require 20 minutes to pass each one, the time required for all will be 140 minutes, or 2 hours and 20 minutes, which corresponds to a horizontal distance, traveled along a level, of 7 miles at the rate of 3 miles an hour. Leakage around lock gates is a serious question in connection with the water supply; is the construction of lock gates studied with a view to stopping these losses? And what terminal facilities, with a proper equipment of hoisting engines, sheds, storerooms, etc., have ever been considered? How should they be designed, how constructed and how arranged so that boats may be unloaded and loaded with the least loss of time? These are a few of the questions which must present themselves to him who examines even cursorily the service of a canal. They and many others are subjects of constant study abroad, and why should they not be so with us? From the nature of our institutions they

cannot be. Rotation in office is fatal to the study of any question for the solution of which time is demanded. Constant changing of the chief of an office or department prevents any settled policy from being carried out, even if some one chief have succeeded in formulating one. With a tenure of office of only one or two years, how is it possible to accomplish any good work, or bring about a lasting result? Scientific problems can be solved only by many years of devotion to collecting facts and data, to assorting and studying them, to interpreting the results and to finding the remedies for the defects. How can this work be done by a series of men, none of whom remain in office long enough to master the details of the work, much less to originate anything for improvement.

How can legislators, who rarely retain their seats for more than one or two terms, act intelligently on such matters? Scarcely do they begin to appreciate the importance of a subject when other persons are selected to take their places, and the modicum of knowledge which the outgoers have succeeded in acquiring is lost, and the incomers have to go over the same ground as their predecessors and learn the needs of the service by the same laborious methods. Legislators, moreover, are rarely schooled in scientific methods of work or in the accuracy of thought necessary for the consideration of these questions. They fail to appreciate the wisdom of the proverb of Solomon: "There is that scattereth, yet increaseth; and there is that withholdeth more than is meet, but it tendeth to poverty."

The condition of the inland navigation of the country can scarcely be called satisfactory. Aside from the Great Lakes and a few of the more important streams, navigation may be said not to exist so far as any practical uses are concerned. For the natural water-ways, which are mostly under the care of the general Government, no systematic plan on a broad and comprehensive scale has ever been adopted, and the writer is not aware that any such plan has ever been proposed. Efforts are made to improve certain streams, but each stream is treated simply as a problem in hydraulics and not as a part of a problem in commerce or transportation. The local conditions and needs of the stream are studied, but not the broad, general plan into which it may be incorporated as a link. Although the work has been localized on different streams, there has been much accomplished. We may take the cases of the Monongahela, Great Kanawha

and Tennessee rivers, all tributaries of the Ohio. Great improvements have been made on these streams; on the first, partly by private enterprise, and partly by government work; on the second and third, by the general Government alone. The main part of the work was done on the Monongahela before the general Government considered either the continuation of the improvement of this stream or the beginning of that of the others. After the work on all of these streams was undertaken, each one was under the charge of a different engineer, and the improvement of each has been carried on according to its own local conditions as a separate stream and not as a part of the great Ohio system, and still less of the greater Mississippi. But can improvements be conducted advantageously in this way if the future development of the country is to be taken into consideration? The worst feature of the case is that the same lack of system must be continued until the necessity of taking a comprehensive view of the needs of the country, in the direction of inland navigation, is forced on our legislative bodies by the strength of public opinion.

While the legislative bodies of the country usurp the functions of the executive no betterment of the case can be expected. On the continent of Europe the studies of what is needed for the improvement of lines of communication under government control are first made by the executive departments. The projects are carefully worked over, and solutions are found for all the problems which the course of the investigation raises. The order in which the various portions of an improvement should be begun is laid down, and the whole project, after having been declared to be of public utility, is submitted to the legislative body, to provide the necessary funds.

How different this system from the lack of system existing with us, where the legislative body originates and determines what is necessary and what is not, and even directs, at times, that a certain sum of money must be expended at a given point without any idea whether the sum mentioned will be too little, enough, or too much.

If the state of the natural water-ways is so poor, what may be said of that of the artificial ones? The canals have to contend, not only against lack of system in construction, but also against constant and vigorous attacks made upon them by their ignorant and prejudiced rivals, the railways, and against the apathy of the public as regards all questions which are not placed close before men's eyes. Persons

interested in railways constantly decry the canals; they claim and proclaim that the day of canals is passed; that canals have outlived their usefulness; that people will no longer submit to the slowness of canal movement in the handling and transportation of goods. This cry is taken up by certain journals (and they are numerous) which will sell their influence for a few free rides, or by others which, having made no deep study of the facts, are misled by the hue and cry started by the railways, which only desire the closing of the canals in order that rates may be raised to the highest point which the traffic will bear. This cry is repeated again by the great mass of the people who "think they think what they are taught," and who repeat like parrots what interested agents and a subsidized press have told them.

Is it true that canals are out of date and that they have outlived their usefulness? Let it be remembered that the canal of to-day varies little from the canal of 50 years ago; and remembering this, let us ask: What would be the probable state of the canals if improvements on them had kept pace with those on the railways? What, if enlarged prisms and more capacious locks had been substituted for the contracted dimensions now in use? What, if boats were propelled at greater speed, so that the distance now covered in two days could be passed over in one? The railway and the canal are both freight carriers. They may be compared to two factories which turn out the same line of goods. How would it be if one of these establishments had gone on as it did 50 years ago, without improvement, while the other had kept itself supplied with all the new machines for saving labor, for preparing the raw material and for turning out the finished product? Would not the former have been ruined long ago and would not the latter, in all probability, have become prosperous? This being so, does it not appear as though there must be a great vitality in the canal, if, having stood still, lo! these many years, it can yet hold its own against all the improvements which have been introduced on the railway?

It would be natural to assume that those who are most interested in having their work made easier and more profitable, the boatmen themselves, would be the first to call for improvements. But such does not seem to be the case. So far as canals are concerned, the mental activity of the carriers seems to be on a par with the traditional speed of their boats. The writer has heard the following objection urged

against the enlargement of the Erie Canal: "If the canal be enlarged, larger boats will be used, and our present boats will be a loss." Of course, the larger boats will drive out the smaller, but meanwhile the smaller boats must remain at work until the whole line is capable of passing the larger boats. The improvement of the canal cannot be brought about in a day, a month or a year. As it continues, the smaller boats can be retired and the improved equipment be obtained. Does a railway hesitate to adapt its track for increasing loads simply because it has on hand a large number of small cars?

Another opposition to the canals comes from the taxpayers. As the Government, whether general or state, has assumed the charge of the water-ways, the funds for their construction and maintenance must come from the public treasury, and hence be obtained by taxation. The people who live at a little distance from the line of the water-way are unable to see the indirect advantages which they gain. They see simply so many dollars paid to the state on account of canals. They do not see to what an extent the canal controls the railway rates of transportation. This is clearly shown by the action, in the Legislature of the State of New York, of the representatives from the counties of the southern tier and those from the northern and north-eastern parts of the State. These counties, being comparatively remote from the canal, do not see the benefits which they receive from it. They forget that the canal made the important cities of New York and Buffalo what they are, and that it developed the smaller towns of Rochester, Utica, Syracuse, and others along its line. They lose sight of the fact that they really receive back in the way of appropriations sums larger than their taxes, the excess being paid by the parts of the state which have become enriched by the canal.

The disregard of the interests of the people, shown by the legislatures of many of the States in neglecting their canals, is little short of a crime. For such action as turning over the canals of a state to the tender mercies of a railway, as was done by the Legislature of the State of Pennsylvania when it abandoned the canals to the Pennsylvania Railroad, it is hard to find a suitable term. It partook of the treachery of Judas. The transportation interests of the whole people of the state were sacrificed to the few who were interested in the railway. Who, traveling along the line of this road, can feel otherwise than sick at heart to see the ruins of the great canal which lay alongside of

the Juniata River; the revetments of its embankments tumbling to pieces; the locks gone to decay; and the rotting remnants of gates and gate posts at such parts of the canal as are not actually occupied by the tracks of the railway? It is a sight which mars sadly, for the thinking mind, the beauty of the country through which the line passes.

Do we find abroad any abandonment of canals comparable with what has taken place in the United States? So far as is known to the writer, Great Britain is the only country where the scare caused by the arrival of the railway brought about the actual giving up of the lines of canals. The story is a curious one, involving as it does cupidity, alarm and lack of investigation. Quoting Professor James again we find that:

"In England one of the circumstances which contributed powerfully to the ultimate victory of the railway was the extraordinary obstinacy with which canal owners clung to their high dividends, refusing to abate one jot or tittle of their high tolls, fighting the railways at all possible points, until railway managers saw that they must concentrate their efforts upon breaking down the canal opposition. Even when the canal owners saw the traffic departing from the canal for the railway, they still refused to take the only course which lay open to them, viz., the enlargement and improvement of the canals and the consequent cheapening of the tolls. When once the break was made in the case of a few great lines, and the fact became became clear that traffic was being rapidly diverted, canal owners became frightened and were willing to take what they could get for their property. It became impossible to get capital for the improvement of canals for two reasons: people began to distrust their permanent prosperity, and the railway mania, which was now fairly under way, absorbed all the capital that was to be had."

In England, as in the United States, the directors of railways saw that the best thing for them to do was to obtain possession of the canals and let them go to ruin. In 1880, in England, Scotland and Wales, out of 4 033 miles of canal and canalized river navigation 1 447 miles were in the hands of railways, 948 miles having passed under railway control in the years 1845–46–47.

Even at their best the condition of the canals was such as to render them unable to compete with the railways, not only in England, but elsewhere. They had been built on absolutely no system at all. They were simply a series of ditches of small cross-section and with insignificant locks wherewith to pass from one level to the next. The widths varied as did their depths; there was no uniform system of

tolls; there were no arrangements for the quick handling and forwarding of freight. The capacity of a line of canal is that of its smallest prism and smallest lock. No matter how great the dimensions of the parts on either side, this smallest part controls the traffic of the whole. Unlike the grade of a railway where an extra locomotive may be used to help over with trains too heavy for one, the canal lock is an insuperable obstacle.

How could such lack of system stand up against the combination of the railways? It was impossible to readjust matters so as to meet the new turn of affairs. The men in control had gone along, undoubtedly, in the old ruts, and when the new opponent appeared they were unable to shake off the lethargy into which they had fallen. The rude awakening dazed their vision. Their sight was dimmed. Apparent ruin stared them in the face. Canal directors are like other people. When a wreck is threatened the cry is, "save himself who can." Undoubtedly the cause would have been far different had the canals belonged to the Government as they did in France and elsewhere on the Continent.

Even in France the influence of the railway mania was seriously felt. Under the reign of Napoleon a systematic development of the canals of France had been begun. Every year the money spent on canals increased in amount, until shortly after the introduction of railways, when the yearly expenditure fell off rapidly for some 25 or 30 years. By that time it was seen that the railways were not omnipotent; that there was traffic better fitted for the canal than for the railroad. Then the annual expenditures began to increase, both for canals and for the canalization of rivers. The invention of movable dams by Messrs. Poirée and Chanoine gave a tremendous impetus to inland navigation, and to the careful study of how best to improve the many streams which, up to that time, had run to waste. The devices and improvements of Messrs. Desfontaine, Girard, Boulé, Caméré, Jacquet, Krantz, and hosts of their fellow-workers, sent France far ahead in this improvement of her natural water-courses, while at the same time the canals were daily becoming more and more a serious study. With the practical adaptability of the French in all fiscal questions, the solution was soon found, and its result was the measure adopted while de Freycinet was Minister of Public Works, in 1879. This great scheme made all the canals of the State,

with few unimportant exceptions, of uniform gauge, if such a term may be applied to a canal. With uniform prisms everywhere, with the length and width of the locks the same in all parts of France, it will soon be possible to send a cargo from Dunkirk or Calais on the North Sea and British Channel to Marseilles on the Mediterranean, to Havre at the mouth of the Seine, or to Bordeaux just off the Bay of Biscay, without breaking bulk or disturbing the contents of a boat. Here, then, was a great advance. But is it sufficient?

In an interesting paper by M. Fleury, on the "Respective Rôles of Water-Ways and Railways in Transportation," presented at the International Congress on Inland Navigation, held at Paris a year ago, we find a partial answer:

"In the east of France, in that very region where the boating interest did so much formerly toward the creation and development of metallurgic, chemical and manufacturing interests, the quantities of heavy materials carried by rail become more and more preponderating. The transportation of fuel to Nancy by water is diminishing, whereas a notable increase marks that by rail. This is especially the case with French coal, of which the amount carried by water was, in 1886, to that carried by rail as 2.63 to 1. In 1889 this ratio had fallen to less than unity. In 1892 it had fallen to less than one-half. Iron ores from Belgium and the North also disappeared for a while from 1887 to 1889, although they now seem to be coming back. Salts and sodas are also showing at the present time a manifest preference for the railway. Cotton also from Havre to many manufacturing towns in the Vosges has largely deserted the canal. In 1890 more than 4 000 tons of this specially profitable freight was lost. The same is the case with wools. Toward the center it is noticed that charcoal, which, from time immemorial, has come to Paris by water, is now beginning to come by rail. On the Central Canal carrying coal from Decize to Creusot has disappeared since 1889. An amount of 70 000 tons, it may be said safely, has given up boats for cars in this one direction alone."

After making many comparisons between the freight rates by water and by rail, M. Fleury informs us that there are other causes than these which have destroyed certain sorts of transportation which the canals used to enjoy. For example: 141 995 tons of coal passed down the Oise in 1889 *en route* to the Lower Seine; whereas, only 108 577 passed in 1890. "This loss cannot be charged with certainty to the railways. It is more than likely that it is due to importations of English coal coming up the Seine, the increase in one year being from

68 000 to 184 000 tons, of which the boating interest got the benefit." Again he tells us that the lowest rates are not those which have done so much to divert traffic from the canals to the railways. For example: the carrying of baled cotton from Havre to the interior has mostly gone to the railroad, although the prices which the boating interest could obtain would still enable them to compete successfully with the roads. "However, in this case, as in many others, the boats have given up the fight. Why must freights by water be to-day so little below those by rail?" This question he answers as follows, and it will be seen that the causes working at home are at work abroad.

"The boating industry," says M. Fleury, "seems too often not to know that there is an inexorable law called progress; those who do not obey it must go under. Boating is now very nearly what it has long been. The traditional shape of the boat might doubtless be improved so as to give less resistance to traction; are not the methods of towing susceptible of being perfected so that, while making movement more regular, it can also be made less costly? But the way in which boating affirms its inferiority, so to speak, as regards railways, is in the lack of organization involving great losses of time and an insufficient use of vessels.

"Railways, it must be acknowledged, have made many and great advances, while boating has been standing still. Locomotives now haul 400 tons of live weight, without requiring more fuel or hands than they used formerly for only 200 tons. Tracks are stronger and better, the rolling stock is better, better oiled, whence a great reduction in resistance. It is vain to say that at $800 a car, the transportation of 300 tons by rail requires $24 000 worth of rolling stock; whereas, a boat of the same capacity only costs one-sixth as much. What does it matter provided that the cars do six times as much useful work as the boat? And this is the case. Since 1886 the railways utilized the capacity of their freight stock 37 times a year, while the boats were used but eight times. Lately the disproportion has become still more marked, although the coefficient of the utilization of boats has increased 11 per cent. Other investigations of the same sort would also lead to the conclusion that, in spite of all scientific reasons to the contrary, the cost of hauling goods by rail is not much greater than that by canal. But, I have just mentioned, it is in violation of the natural laws observed by science that the poor organization of the boating service, its routine, its distrust of new methods, its dislike for change of habits, have given rise to this shocking anomaly and allow it to exist. Boating must change if it is to continue to exist. Let it perfect its boats and improve its methods of moving its vessels. This will be accomplishing much; but, above all,

let it use its time better on the road and in those frequently long stops at ports while seeking freights in any haphazard way. Let all this be aided by a reduction in the minimum time required for passing a boat through a lock and in that needed for closing the canal for repairs. By this better use of time boating will be more sure of success in maintaining and increasing its business : rates of four-tenths of a cent per ton per mile will no longer scare it, and it will be long ere the railways can follow down to such a figure. It will remain in control of the part of the carrying trade which tradition still continues to give to it. It will have served the interests of the public as well as its own."

M. Fleury then refers to the law of 1879, which calls for a minimum depth of 6.56 ft. in the canal and locks having an available length of 126.28 ft. and width of 16.40 ft ; he calls attention to the great injury done to navigation by not having the application of this law extended to all lines of canal in the country, and then urges the completion at the earliest possible moment of this great and advantageous improvement.

In spite of the dark picture drawn by M. Fleury, it will be found in a paper presented at the same congress by M. Delaunay-Belleville, that the tonnage carried by the French lines of inland navigation amounts to the respectable figure of 1 997 181 540 mile-tons for the year 1890. The railway mile-tonnage for the same year was 7 292 391 218. Hence, the freight carried by the inland lines of navigation was 27.3% of that carried by all the railways combined. The length of the waterways frequented by boats is 7 946 miles, the length of the railways is 20 667 miles ; hence, the water tonnage reduces to 251 000 tons carried the entire length of the navigable highways, and the rail tonnage to 353 000 tons carried the whole length of the railways. The average activity per mile of water-way is therefore about $\frac{7}{10}$ of the average activity per mile of railway. Finally, the average distance of transportation of a ton of freight was 79 miles by rail and 82 miles by water.

The total quantity of freight embarked on the navigable highways in 1890 reached 24 167 343 tons. The total tonnage of the French seaports, including arrivals and departures, and the three great classes of trade "Foreign, Deep-Sea Fisheries, and Coasting," was 24 814 497 tons in the same year, 1890.

The freight carried is grouped under ten different heads: Coal, building materials exclusive of wood, manures and fertilizers, firewood and timber, machinery, metallurgic industry, industrial products, agricultural products and provisions, miscellaneous articles, wood of

all sorts moved in rafts. These may be reduced to three grand divisions: 1st, products of the extractive industries, such as coal, building materials, ores and mineral fertilizers; 2d, forest and agricultural products and food supplies (including vegetable and animal manures); 3d, metallurgic and industrial products and miscellaneous articles. The quantities carried are—

Of the first class	16 161 905
" second class	6 100 045
" third class	1 905 393

The increase in the navigation traffic from 1881 to 1890, both inclusive, is as follows: the actual tonnage of freight loaded on board rose from 19 740 239 tons in 1881 to 24 167 343 in 1890, or an increase of 22.4%; the total mile-tonnage rose from 1 350 383 817 in 1881 to 1 997 181 540 in 1890, or an increase of 47.8%; the average length of haul was increased from 68.5 to 83 miles. Hence, not only did the commercial importance of the traffic increase more than 22% during this last decade, but the use of the water-ways was greatly improved, since the average length of haul of 1 ton was increased 21 per cent.

A comparison between the railway and water freights shows that the mile-tonnage increased on the canals 4.8% per year during the decade; whereas, on the railways it increased less than 1% per year in the same time.

M. Delaunay then says: "The increase in the use of the water-ways must be attributed almost exclusively to their constant improvement, the increase being not less than 21%; it cannot be doubted that the gradual removal of the breaks in the uniform gauge of the canals has allowed the boats to make longer and longer trips without breaking bulk."

This sameness of gauge has been carried over a length of 1 556 miles between 1878 and 1890, and it now (1890) rules on a length of 2 462 miles of the French canals.

A great drawback to the full usefulness of the French canals is to be found, according to M. Delaunay, in the lack of technical and commercial equipment, that is, proper machines for handling, and suitable wharves, sheds, etc., for storing and sorting goods. This lack he compares with the admirable equipment of the seaports and of the large railway stations.

Large industrial establishments have frequently their own landing places, which are thoroughly well provided with everything needed

for handling freights and for storing them. "Collieries have their banks provided with all necessary machinery to load their coal under the best conditions and with a minimum of expense and waste. In the same way large consumers of fuel who settled alongside of canals and navigable streams, in order to obtain their supplies cheaply, have not been slow to provide the equipment fitted to the economical reception of their fuel.

"The same holds good with other branches of inland trade, building materials, grain and flour, wines, etc.; everywhere large producers and large consumers, guided by their interests, have set up the private plant suited to the needs of their industries.

"But wherever the interests of the public at large are in question, wherever powerful individualities have not had to interfere in their own behalf, the equipment is either lacking, or it is notoriously insufficient."

In summing up all his data M. Delaunay lays down a number of propositions, of which the following are especially germane to the subject of this paper. They are:

"The radius of attraction or expansion of inland navigation ports over the surrounding country is exceedingly limited. This situation, which follows from the nature of the freights which are the main reliance of this navigation, has not changed sensibly by reason of the insufficiency of the technical equipment (machines for loading and unloading) of the public ports, of their commercial equipment (sheds, storehouses and warehouses), and of the almost complete absence of connection between the water-ways and railways.

"The isolation of the navigation system from the railway system is a great economic blunder. Large industrial establishments have known, in their private interests, how to set an intelligent example of the simultaneous use of both means of transportation; but again most of the public ports are without the necessary appliances.

"This close connection of the rail to the wharf * * * will thus make the ports of inland navigation, not only points of industrial consumption or storage of food supplies, but true centers of commercial transactions.

"This commercial extension cannot take place without giving rise to an increase of trade from which both the boating interest and the railways will profit."

M. Delaunay's final conclusions are:

"1st. So far as the highway proper is concerned, the completion of the uniform gauge of the water-ways of the first class is the first necessity; 2d, so far as the special organization of the ports is concerned, a close connection of the water-ways with the railways is demanded."

It may not be without profit to glance at affairs in Germany, and especially in Prussia, where enormous sacrifices have been made for the improvement of the water-ways since 1880.

At the Fifth International Congress on Inland Navigation, M. Pescheck presented an interesting paper on the "Respective Rôles of Water-Ways and Railways in the Movement of Merchandise in the Basins of the Elbe and the Oder." From this paper it is learned that the basins of these streams and their tributaries cover about three-fourths of the German Empire. Within their limits are the three largest cities of Germany; Berlin, Hamburg and Breslau. Dresden, the capital of Saxony, and the great commercial cities of Magdeburg and Stettin, are also included.

After giving a brief summary of the features of these basins from the commercial standpoint we learn that—

"Prussia has undertaken to transform her water-ways so as to make it possible to carry cheaply and to great distances the goods best adapted to this form of transportation. On account of the different characters of the various basins it was impossible to lay down a given boat as a type. Only the execution of such a plan could be followed as would insure, on the one hand, a sure and quick circulation, and allow, on the other, not only the use of the present vessels and increased loads, but also the employment of large boats on deeper water. The necessity of using steam has not been lost to sight, that is, the increase in the number of towboats and steam carriers. This programme means an endeavor to have steamboats circulate freely on the canals, involving in the beginning heavy costs for strengthening the banks. To obtain these results Prussia has spent $12 500 000 since 1880," an average of about $1 250 000 a year.

The extension of the water-ways is marked by the following considerations : 1st, the large rivers of Northern Germany are naturally good highways, and this leads to joining their basins by canals ; 2d, interest and national cultivation demand the regulation of the large rivers with a consequence of favoring navigation ; 3d, the improvement of navigation leads to the improvement of the old canals and the opening of new.

The greater part of the water-ways are now in such condition that shippers and consigners of goods are able, as they could not formerly, to agree as to times of delivery. Hence more valuable freights now go by water than those formerly intrusted to boats.

A comparison between the amounts of wood, coal, wheat, rye, flour

and bran, pig iron and manufactured iron, carried by rail and by water, shows that of the total number of tons carried there went—

Of wood	66%	by rail and		34%	by water.
" coal	83	"	"	17	"
" wheat	58	"	"	42	"
" rye	32	"	"	68	"
" flour and bran	62	"	"	38	"
" pig iron	62	"	"	38	"
" manufactured iron	95	"	"	5	"

These figures apply, however, only to the six towns mentioned. For them the freights by rail are 75% of the total amount carried, and those by water are 25 per cent. The freights of the entire valleys are distributed thus : 89% by rail and 11% by water.

These comparisons show the large part played by the water-ways in the exchange of goods, in spite of the relatively very small importance of their branches as compared with those of the railways. There is reason to hope that this part will become greater as imperfections are made gradually to disappear. The establishment of a proper equipment for loading and unloading vessels has not kept pace with the development of navigation. Hence, out of the 300 days, about, in the year, during which navigation lasts, a boat is in motion only 75 days, the other 225 being given up to loading, unloading and waiting.

In Germany the State owns the railways as well as the water-ways. The development of the water-ways was scarcely disturbed when the railway system was extended. Where it was felt, a remedy was soon applied by pushing more energetically the development of the water-ways.

Under the peculiar economic conditions it is found that a canal scarcely becomes profitable until the annual amount of freight carried reaches 1 000 000 tons, and that water rates are not quite so low as rail rates. Still, there are some well-informed partisans of water-ways who maintain that water-ways, when rationally constructed and equipped, can compete perfectly well with railways.

"If, standing only on the calculation of net rates for transportation, it were desired to stop a future development of water-ways to the profit of the railways, it could not help doing harm to economic considerations. Every transportation route has a right to the protection

of the public ; because civilization is propagated by facilitating every kind of communication."

M. Pescheck quotes M. Krantz, a government engineer and a senator, who used the following language at the session of the French Senate of June 12th, 1884:

"Why can canals still have at the present time earnest and convinced partisans?—and I confess to being one. It is not that any one can look upon the canal as being so complete an instrument as the railway, or nearly so; for it is not. * * * The canal brings about economy, not only by the reductions of rates which it makes, but also by those which it imposes. It is the check on the railway; and if, recalling my profession as an engineer, I could use a comparison, I should say that it is a brake—an automatic brake; no one is needed to make it work; it acts on the demand of surrounding forces; that is, of private interests. * * * It is the brake—the necessary and legitimate brake—on the railway, which preserves the government from all sorts of severe measures which it would frequently adopt and which would be rarely successful."

In Prussia no attempt is made to bring about competition between the railways and water-ways, as that is spontaneous; it comes of itself.

M. Pescheck concludes as follows:

"*First.*—The regulation of large streams by means of dikes, with the object of insuring the free flow of water at low and medium stages in an invariable minor bed, so as to prevent marshes forming along the shores, favors navigation and causes the improvement of canals, without bringing about competition with the railways.

"*Second.*—Heavy transportation can be carried on by rail and by water equally well; and the more the water-ways and their means of transportation are improved, the more they will be sought by less cumbersome freights.

"*Third.*—In order to compete with the railways, the water-ways require, above all, a more complete equipment for loading and unloading goods.

"*Fourth.*—The parts to be played respectively by the railways and water-ways of a given country depend especially on the natural conditions existing for navigation, and also on the politico-economical considerations controlling the movement of freights.

"*Fifth.*—Water-ways are more easy and effective means than special railway rates for enabling the entire public to participate in the cost of transportation on a large scale, the cheapness of which is indispensable for the prosperity of industry and agriculture.

"*Sixth.*—The creation of artificial water-ways is justified economically, as a general rule, even when the cost of construction and maintenance can only be made up by the saving accruing to the shipper

with respect to railway rates; and there is no reason to fear that the railway will be at all injured by the creation of canals."

The papers presented to the Fifth International Congress on Inland Navigation show how widely the subject of water transportation is engrossing the attention of engineers and political economists. Naturally, such conventions must call attention to their work, and the opinions which they utter must have weight. Are these conventions the forerunners of public opinion, or is the great mass of the people gradually becoming aware that there are better ways of checking the exactions of railways than a resort to tariff commissions? The testimony of Mr. Albert Fink, for a long time the head of the railway pool of the United States, is valuable in this respect. In speaking of the Erie Canal, in a letter to Senator Windom in 1878, he says:

"You are aware, sir, that when the rates are reduced between Chicago and New York, as they are always reduced on account of the opening of the canal, that this reduction applies, not only from Chicago, but from all the interior cities (St. Louis, Indianapolis, Cincinnati) to New York. If that were not the rule the result would be that the roads running from these points to Chicago would carry the freight to Chicago from which low-water or rail rates would take it to New York and thus leave the through lines from the inland cities without traffic. Hence, Philadelphia, Baltimore and Boston, though they have no direct water competition, get the advantage of reduced rates. The reduction of rates from Chicago and St. Louis to New York, Philadelphia, Baltimore, etc., reduces rates on shipments from those western points *via* New York and the ocean to Southern Atlantic ports, Norfolk, Wilmington, etc., and from there into the Interior, Augusta, Macon, etc. The direct railroads must reduce their rates correspondingly, and thus the Erie Canal determines rates all over the country, including the South, until it reaches a line where low ocean rates from New York to the Gulf cities exercise their influence upon the rates to adjacent interior points."

Here is M. Krantz's expression, that the canal is a brake on a railway, put in another shape. No one understands the transportation problem better than Mr. Fink. For this reason his words have a weight greater than those of any other man.

That the people have long had the idea that freight rates by rail are exorbitant is shown by all sorts of acts of Congress and acts of State legislatures intended to put a check on the railways—railway commissions, commerce, and inter-state commerce commissions have been created with the express intention of regulating railways. In

other words there has been an endeavor to create economic conditions by law, by mere words. It is just such a corrective as might be expected from bodies composed mainly of lawyers and not of business men. Such measures are the severe ones of which M. Krantz speaks, and which, he says, are rarely successful.

The inability of such measures to remove the abuses which they are intended to correct is causing an investigation by those interested into the means whereby a true corrective may be found. The people are gradually awakening to the fact that the true solution of the problem is by the improvement of the water-ways now existing and by the establishment of new ones. No argument can be made in the face of such a competition. No unjust and discriminating rates can be maintained by railways when the latter know that a powerful competitor stands ready to take advantage of any shortcomings. No long suits at law, with all the advantages on the side of the railways which a long purse, well-paid, and frequently unscrupulous, attorneys give, have to be borne by the unjustly treated shipper before he can obtain justice. With the water-way the remedy is at hand; it can be applied promptly and effectively. It is a remedy without appeal. This the railways know well.

Now what must be done to bring about the remedy? As all public improvements in our country must originate in the legislative bodies, and as these bodies possess, as a rule, no more information on any given subject than the masses of the people, it is necessary to begin by educating the people to the true functions and capacities of water-ways. In other words, public sentiment must be aroused on the subject, because to this sentiment the legislative bodies are generally most sensitive. Means must be taken to keep the subject of water-ways before the people. The construction and maintenance of such ways being under the control of the Government, there are no stocks or bonds to be put upon the market, and these ways are not listed at the exchange. They lie, therefore, in the background, and remain there unperceived, unless they be brought by force to the front.

The improvement of the natural water-ways presents special problems. In some the supply of water all the year round is sufficient to keep up a good navigation, provided that it be practicable to confine the stream to an artificial minor bed. In others a slack-water system, by means of locks and movable dams, will be required. In both cases

there must be a proper arrangement of landings, space in which to store freight before loading and after unloading, and special appliances for handling freight promptly.

The improvement of the artificial water-ways requires consideration according to the position which the canal holds in a chain of transportation. Where it is a highway of the first order it must be adapted to boats of large size. For a canal of such importance as the Erie, the boats should have a freight displacement of not less than 1 000 tons. The locks should be proportioned to the capacity of the trunk of the canal. It is stated that the present trunk of the Erie Canal is sufficient for boats of 650 tons, but the locks are only large enough for boats of 250 tons.

The water supply of the canal needs careful attention. A large gain in this could be made by withdrawing all privileges of taking water from the canal for any purpose whatever.

The banks of the canal must be protected to such an extent that boats can pass at a speed of at least 10 miles an hour.

At every town there should be proper places for landing cargoes. On these landings should be the necessary machinery for handling freight and the buildings in which to store it. In this connection there is a subject which must be settled before long, and that is the way in which railways have been allowed to cut off many ports from the water. Witness most of the ports of the Great Lakes! The railways, through the connivance of the authorities of several cities, have built their bulkheads and laid their tracks right on the edge of the water, and shut off the city entirely from all communication with its own water front. Under these circumstances there is no advantage from navigation to be gained by the city, because everything which reaches it is filtered through the railways which surround it, and it obtains by sufferance that which belongs to it as a right.

The motive power on the canal must be adapted to the new conditions. The days of the horse are numbered, and steam, for the present at least, must take his place. This change need not be prejudicial to the canal, because the shape of the boat may be so changed as to cause little more wash with the greater speed than there is at present with the one now in vogue.

System must be introduced in the methods of doing business. Shippers must be taught that the canal exists. Freights must be

solicited and rates made through to various points by connection with railways or steamers from the termini.

In a word, the canals must be brought up to date. They must have the benefit of the knowledge and skill of which there is such an abundance at the present day. If, when the canals become thoroughly modernized, both in appliances and in methods, a comparison be made between their capacity and that of the railways for doing business, we may rest assured that the last chapter on the subject of inland navigation will remain long unwritten.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

606.

(Vol. XXIX.—July, 1893.)

HISTORY OF THE CONVERSION OF THE RIVER CLYDE INTO A NAVIGABLE WATER-WAY, AND OF THE PROGRESS OF GLASGOW HARBOUR FROM ITS COMMENCEMENT TO THE PRESENT DAY.

By JAMES DEAS, C. E., Engineer Clyde Navigation.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The writer has much pleasure in complying with the invitation of the American Society of Civil Engineers, and has prepared this paper on the improvement of the River Clyde for navigable purposes, and the progress of the Harbour of Glasgow from its inception until the present day. In 1715 the first act was passed for quayage at Glasgow, the money to pay for which was obtained out of a duty of two pennies, Scots, or one-sixth of a penny sterling, on every pint of ale and beer that was vended or sold within the City of Glasgow, and privileges thereof.

Entered according to Act of Congress in the year 1893, by the American Society of Civil Engineers, in the Office of the Librarian of Congress, at Washington.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Probably for no river in Great Britain has so much been done "by art and man's device" as for the River Clyde above Port Glasgow. In fact, from a mile below Bowling upwards to Glasgow, a length of 12 miles, the Clyde of the present day is nearly as much an artificial navigation as the Suez Canal.

It is but natural that American engineers should desire to have some information regarding the improvement of the Clyde, which, though not the birthplace of steam propulsion in Europe—Dalswinton Loch, Dumfriesshire, having that never-to-be-forgotten honor 104 years ago—received into its waters at Port Glasgow in June, 1812, the *Comet*, 42 ft. long by 11½ ft. beam, 4 ft. draft, and 3 H. P., the precursor of the mighty fleet of steamships of the present day; and has played so important a part in the development of the mercantile and defensive steam navies of the world, especially in the transatlantic trade, which has brought New York and Great Britain within six days of each other, and has culminated for the present in the launching into the Clyde, within a half mile of the western boundary of the City of Glasgow, on September 8th and February 2d last, respectively, from the Fairfield Shipbuilding and Engineering Company's yard, of the steamships *Campania* and *Lucania*, each 620 ft. long by 65 ft. 3 ins. broad by 43 ft. deep.

These improvements have raised Glasgow within the short period of 90 years from a second-rate inland provincial town, with a population of 77 000, to be the second city of the Empire, with a population of 658 073, and the chief seaport of the west of Scotland; increased the value of the lands on the river's sides, from Glasgow seaward, a hundred-fold; created the burghs of Govan and Partick; given wealth to thousands, and the means of life to hundreds of thousands of the inhabitants of the northern portion of Great Britain, and emphasized in a marked degree the local epigram, "Glasgow made the Clyde, and the Clyde made Glasgow."

"The Tweed, the Annan, and the Clyde
All rise from one hillside."

But how different their careers and destinies! The Tweed, immortalized by Sir Walter Scott, falling into the North Sea at Berwick, and famous chiefly for its king of fish, the salmon; the Annan, after a quiet and pastoral course of only 35 miles, reaching its bourne in the Solway Firth at Annan; while the Clyde, after a course of 98 miles and

draining an area of 945 square miles, reaches deep water at Greenock, and thence to the Atlantic Ocean passes in its course over the famed Falls near Lanark, through the celebrated orchards of Clydesdale between Lanark and Hamilton and thence to Glasgow through the wealthy mineral district which it drains; is famed the wide world over as the creator, by its improvement, of the City of Glasgow, the home of almost every industry under the sun, and is the greatest ship-building river in the universe, furnishing to all nations the means of communication with each other by vessels built on its banks.

Numerous waters, rivulets, burns and rills join in the formation of the upper Clyde; the highest of these, which take their rise in the mountain ranges on the confines of Lanarkshire and Dumfriesshire, are the Daer Water, the Powtrail Water, and the Clyde Burn; the last 1 028 ft. above ordnance datum, where it crosses under the Caledonian Railway at the Summit Station, in a conduit 12 ft. 6 ins. wide by 2 ft. 3 ins. high.

The Daer and the Powtrail meet before their confluence with the Clyde Burn; and although the Clyde Burn is considerably smaller than either of the other two, the stream from this point takes the name of the River Clyde.

The chief tributaries of the lower Clyde are only three in number.

First.—The Kelvin, noted in song, which rises in the Campsie Hills, due north of Glasgow, forms in its lowest reach the western boundary of the City of Glasgow, and, after a course of only 21 miles, discharges into the Clyde at Govan Ferry, the western limit of the harbour.

Second.—The Cart, which joins the Clyde about ½ mile below Renfrew, and is formed by the junction, about ¾ mile from the Clyde, of the White Cart and the Black Cart; the former, about 19 miles in length rising in the Eaglesham District of Renfrewshire, about 10 miles due south of Glasgow, and on which the prosperous town of Paisley is built; and the latter, about 9 miles in length, rising in the neighbourhood of the town of Lochwinnoch.

Third.—The Leven, well known in cotton manufacturing circles for its Turkey-Red Dye Works, which discharges the surplus waters of Loch Lomond—the Queen of Scottish lakes—ruddy coloured, into the river immediately west of Dumbarton Rock after a course of 7½ miles, and on which the town of Dumbarton stands, erstwhile famed for its glass works, but in the present day better and more widely known for

the extensive ship-building and marine engineering works of Messrs. William Denny & Brothers, and Messrs. A. McMillan & Sons.

The Clyde in its course to the sea, unfortunately for its character for salubrity, receives both the domestic and manufacturing sewage of upwards of 1 000 000 inhabitants and the 41 957 000 galls. of water which Glasgow daily uses, 37 193 000 galls. of which are from Loch Katrine, add to its volume.

The Forth and Clyde Canal, 35 miles long, opened in 1790, whose locks admit of the passage of vessels 68 ft. keel, 19 ft. beam, and 8½ ft. draft of water, joins the Clyde at Bowling; and a branch from the canal to the Clyde opposite the mouth of the Cart gives direct communication between the canal and Paisley.

The writer will, in dealing further with the subject, put his remarks under the following heads :

1. History of the Improvement of the River.
2. Progress of the Harbour.
3. Rise and Progress of Ship-building on the River and its Tributaries.
4. Short Description of Other Harbours on the River.

1. History of the Improvement of the River.

In prehistoric times ancient Britons must have paddled their own canoes in its shallow stream, as dugouts have been unearthed, not only on the banks of the river, at Glasgow and at Bowling, but even at the Cross of Glasgow, fully 500 yds. from the present margin of the river; and Roman legions must have encamped on its banks while they were engaged in constructing, under Agricola, A. D. 80–81, a chain of forts between the Clyde near Bowling and the Forth near Bo'ness; and under Antoninus Pius, A. D. 140, in connecting these forts by ramparts of earth and stone, with a deep and wide ditch outside and a paved military road along the inner or south side, to check the inroads of the Caledonian barbarians.

Upwards of 300 years ago—in the summer of 1566—the Magistrates and Town Council of Glasgow made the first attempt on record to improve the river. Detachments of the inhabitants of the City of Glasgow, joined by contingents from Renfrew and Dumbarton, endeavored to open up what the chronicler of that day called "a formidable sandbank" at Dumbuck, about 2 miles above Dumbarton and about

12 miles below Glasgow, at which they laboured for several weeks, residing during the time in timber huts built near the scene of their operations. This attempt must have proved of little value, as Thomas Tucker, one of Cromwell's commissioners, describing Glasgow and the river in a report, dated November 20th, 1656, 90 years thereafter, says:

"The situation of this towne in a plentiful land, and the mercantile genius of the people, are strong signs of her increase and growth were she not chequed and kept under by the shallowness of her river, every day increasing and filling up, soe that noe vessels of any burden can come nearer up than within fourteene miles, where they must unlade and send up theyr timber and Norway Trade in rafts or floates, and all other commodityes by three or foure tonnes at a time in small cobles or boates, in three, four, five, and none above six tonnes a boat."

Nor can much benefit have resulted from the carrying out of the following Minute of Council, dated May 8th, 1740:

"The Council agree that a tryall be made this season of deepening the river below the Broomielaw, and remit to the Magistrates to cause do the same, and go the length of £100 sterling of charges thereupon, and to cause build a flatt-bottomed boat to carry off the sand and chingle from the banks."

Up to 1768 the river between Glasgow and the sea remained practically in a state of nature, choked up with sandbanks, impeded by numerous fords, and only suitable for herring boats and such like craft. Thus the river remained, expanding in useless width as it decreased in depth, until in that year, John Golborne, civil engineer, of Chester, appeared on the scene, and it is to him that Glasgow is indebted for the first really successful step in the improvement of its navigation. By his system of contracting the river by the construction of rubble jetties and the removal of sand and gravel shoals by ploughing, harrowing and dredging, the first marked improvement of the navigation was effected.

In 1773 he took a contract to make Dumbuck Ford 6 ft. deep and 300 ft. wide at low water for £2 300; and in September, 1775, the Town Council, on the recommendation of the merchants, gave him £1 500 for deepening the river 10 ins. more than he was bound to do by his contract, presented him with a silver cup, and gave his son £100. Generous Town Council! Happy engineer!

By an Act of Parliament passed in 1809, the Lord Provost, Magistrates, and Council of Glasgow, under whose control the improvement of the river had up till then been carried on, were constituted Trus-

tees of the Clyde Navigation, and were given power to deepen the river until such time as it was at least 9 ft. deep at high water, neap tides, between Glasgow and the Castle of Dumbarton ; and, by an Act passed in 1825, they were authorized to appoint, as trustees, five other persons interested in the trade and navigation of the River and Firth of Clyde, and to deepen the river from Glasgow to Port Glasgow till such time as it was at least 13 ft. in depth.

The constitution of the Trust continued thus until 1858, when it was materially altered by an Act of Parliament passed in that year and still in force, the number of the Trustees being fixed at 25, one being the Lord Provost, nine Town Councilors, and the remaining 15 representatives of the shipping, mercantile and trading interests of Glasgow, of whom two are chosen by the Chamber of Commerce of Glasgow, two by the matriculated members of the Trades House of Glasgow, and nine by ship-owners and rate-payers. The qualifications of the Trustees to be elected by the ship-owners and rate-payers is ownership to the extent of at least 250 tons in any vessel or vessels registered at the Port of Glasgow, or payment of rates to the extent of £25 or upwards per annum ; and of electors, ownership to the extent of at least 100 tons, or payment of £10 or upwards of rates per annum.

From 1781 until 1836, the works carried on for the further improvement of the river under the direction consecutively of Golborne, Rennie and Telford, consisted chiefly in the shortening of some, and the lengthening of others, of Golborne's jetties, the construction of additional jetties, the connecting of the outer ends of these jetties by half-tide training walls on both sides of the river so as to confine the water and increase the ebb scour, and the removal of hard shoals by dredging.

It was not till 1836 that the river from Glasgow to Port Glasgow was treated as a whole, and a true appreciation shewn of its future by the Clyde Trustees' then engineer, Logan, in the laying down of river lines, which, with some slight modifications and expansions, have, up till now, formed the limits of the river's improvements.

Parliamentary plans on these lines, approved of by James Walker, Consulting Engineer to the Trustees, were submitted to and sanctioned by Parliament in 1840 ; but so inadequate was the appreciation of the depth required, that 20 ft. at high water, neap tides, was recommended

by Logan as the extreme depth of the river and harbour, and a clause in the Act empowered the deepening to proceed until every part thereof shall have attained at least a depth of 17 ft. at high water, neap tides.

The depth in the Harbour of Glasgow, and in the river at the present time, is from 27 to 29 ft. at high water, neaps; high water, springs, being about 2 ft. higher. The average tidal range of spring tides at Glasgow is 11 ft. 2 ins., and at Port Glasgow 10 ft., and of neaps at Glasgow 9 ft. 2 ins., and at Port Glasgow 8 ft. 3 ins.

While jetties and training walls, or parallel dikes, performed a useful part in the early improvement of the river, it is to persistent dredging that the enormous increase in the magnitude of the river since 1840 is due.

The early dredging was performed by large rakes, or porcupine ploughs as they were called, because they were provided with strong iron teeth, wrought by hand capstans, which drew the material from the bed of the river on to the banks.

Hand-wrought, and subsequently horse-wrought, dredgers, with small buckets on a ladder, succeeded the plough, and in 1824 the first steam dredger was started on the river. It dredged only to 10 ft. 6 ins. Now, several of the dredgers employed can work in 35 ft. depth of water; and there has been added to the fleet within the last few months the most powerful dredger afloat, which can lift 600 tons of sand from a depth of 40 ft. in one hour by a chain of buckets on a steel ladder, each bucket containing 22 cu. ft.

It is undoubtedly to the application of steam power to dredgers, and the subsequent adoption of steam hopper barges—a French invention—for carrying the dredged material to the sea, that the rapid enlargement, not only of the Clyde and the Harbour of Glasgow, but of the Tyne, the Tees, and several other similar rivers, in recent years is due. But for the introduction of the latter, it would have been physically, financially and otherwise impossible to have disposed, within so limited a time, of the enormous quantities of material which have been dredged from these various rivers and harbours.

Up to 1862 all the material dredged from the River Clyde and Harbour of Glasgow was loaded on punts holding 8 cu. yds., and deposited on the alveus, or foreshores, or the low-lying land adjoining the river. Many acres were thus reclaimed, to the aggrandisement of

the riparian proprietors, to whom the Trustees were required to hand over the ground free of cost.

The adoption and speedy acquisition by the Trustees of steam hopper barges, holding from 240 to 320 cu. yds. each, removed all these obstacles and enabled the deepening, widening, and straightening of the river and harbour to be proceeded with more rapidly, without hampering the Trust's finances, or seriously obstructing the navigation with steam-tugs and trains of punts. The result has been that, while in 1861 the total quantity dredged and deposited on land was 593 176 cu. yds., the total quantity dredged in 1892 was 1 598 984 cu. yds., only 65 752 cu. yds. of which were deposited on land. The total quantity dredged during the last 48 years amounts to 39 511 418 cu. yds. To enable the material dredged in the deepening of the river to be more economically disposed of, two twin-screw barges, each of 1 000 tons hopper capacity, were added simultaneously with the new dredger.

The best thanks of river and harbour authorities, such as the Clyde Trust, of River and Harbour Engineers, and of the community at large, are justly due to those marine engineers and ship-builders who have made dredging plant a specialty, among whom the firms of Messrs. William Simons & Co. and Lobnitz & Co., Renfrew, and Fleming & Ferguson, Paisley, occupy deservedly prominent positions.

In 1755 the Clyde at Glasgow was only 15 ins. deep at low water, and 3 ft. 8 ins. at high water, while the depth at Marlinford, 3 miles below the harbour, was 18 ins. and at Erskine, or Kilpatrick Sands, about 8 miles below and at Dumbuck Ford 10 miles below, only 2 ft. at low water.

In 1781 the depth at Dumbuck Ford was 14 ft. at low water ; it is now 20 feet.

In 1806 Telford reports that on February 14th of that year the *Harmony*, of Liverpool, came up with the ordinary spring tide, drawing 8 ft. 6 ins of water; but up to 1812 the river, from the harbour downwards to Bowling, was so shallow that it was necessary for the *Comet* to leave Glasgow and Greenock respectively at or near high water, to prevent grounding in the river.

An old gentleman, who had been connected with the Clyde navigation for upwards of 50 years, informed the author a few years ago that he made a voyage in the *Comet* in 1812, leaving Greenock at 10 A. M. for Glasgow. It was 2 P. M. before they got to Bowling, 10½ miles above

Greenock, in consequence of a ripple of a head wind, and from there all the passengers had to walk to Glasgow owing to the lack of water, the tide having ebbed. As late as 1815, a traveler by that steamer records the fact that he left Glasgow in the morning and arrived at Greenock after a seven-hours' passage, three hours of which were spent lying on a sand-bank at Erskine. Lighters not drawing more than 4½ ft. have been known, owing to neap tides and consequent groundings, to take six weeks to make the voyage from Greenock to Glasgow and back; and while all but two of the first 20 steamers built on the Clyde had their engines made by Glasgow engineers—the engines of the excepted two being made by Boulton, Watt & Co., Soho—their hulls were built at Dumbarton, Port Glasgow and Greenock.

Flyboats for passengers, with sails and oars, were used before the introduction of steamboats, a whole day being spent frequently in the passage between Glasgow and Greenock. Steam-tugs for towing the lighters followed soon after the introduction of passenger steamers, and in recent years steam has been extensively applied to the lighters themselves.

Before the year 1818 none of the vessels in the foreign trade came further up the river than Greenock or Port Glasgow. Their cargoes were there discharged into lighters, which carried them to Glasgow, and at that date the largest ship belonging to either Port Glasgow or Greenock did not exceed 400 tons. In 1821, vessels drawing 13½ ft.; in 1830, drawing 14 ft.; in 1840, 17 ft.; in 1850, 19 ft.; in 1870, 21 ft.; in 1880, 23 ft.; and in 1892, 26 ft. 5 ins., came up the river; while steamers with a draft of from 23 to 24½ ft. now pass up and down the river almost daily, leaving Glasgow and Greenock respectively about an hour or so before high water, and passing over the navigation between these points in two hours.

The river, cross-channel and other steamers, of 16-ft. draft and under, leave Glasgow and Greenock respectively at any state of the tide. The towing of sailing vessels between Glasgow and Greenock by steam-tugs is now nearly universal. Small sailing craft are formed into trains, and each train is towed by one tug. Deep-drafted sailing vessels and the large transatlantic and other foreign-going steamers have a tug each to take them round the quick bends, and the largest class have generally a tug ahead and a tug astern.

The bed of the river from Glasgow to Port Glasgow is now virtually

level throughout, and 7½ ft. of the 9½ ft. increased range of tide in Glasgow Harbour, and the whole present depth of from 16 to 20 ft., at low water, spring tides—together 23½ to 27½ ft.—has been obtained by dredging out the bottom of the river.

As may be readily supposed, groundings in the river were of frequent occurrence in the earlier days of the river's improvement, shipowners being prone to load their vessels to the utmost capacity of the deepened river, making too little allowance for tides nipped by frost or east winds. But at length the deepening has got the better of the deep loading, so that, while in 1871, 59 vessels grounded between Glasgow and deep water at Greenock—two of them below the Clyde Trustees' western boundary, the registered tonnage of the largest of which was 2 069 tons, and the greatest draft 21 ft. 7 ins.—in 1892 only nine vessels grounded, the registered tonnage of the largest being 3 613 tons, and the draft 26 ft. 5 ins.

In 1800 the time of high water at Glasgow was two hours behind Port Glasgow; now it is only one hour. Even as late as the summer of 1858, a float put into the river at Glasgow Bridge, at the first of ebb, took 537 hours, or 43½ tides, to reach Port Glasgow, a distance of 19.4 miles; while in the summer of 1881, a float, under exactly similar conditions, reached Fort Matilda, below Greenock, a distance of 23.5 miles, in 86 hours 20 minutes, or seven tides.

Any history of the improvement of the river would be incomplete if reference were not made to the removal of Elderslie Rock, a huge vein of trap which extends across the river a short distance above Renfrew. In the early report of the condition of the Clyde, no mention is made of this rock, but the Blawarthill Sand—one of the many shallow fords on the river—was situated where the rock was subsequently found, and in 1755 there was a depth on this sand of only 18 ins. at low water, and 4 ft. 9 ins. at high water. It was not till 1854 that its existence was discovered by the grounding on it of the *Glasgow*, one of the first steamers trading between Glasgow and New York, which, while passing up the river, struck upon it and knocked a hole in her bottom. It was at first thought that it might be a large boulder that had done the damage; but borings showed that it was rock, that it extended over an area of the bed of the river 925 ft. in length by 320 ft. in breadth, and that it was a hard whinstone or trap dike.

From the time of its discovery till the beginning of 1869, boring

from a movable stage and by diving bell, and blasting with gunpowder, at an expenditure of £16 000, had given a minimum depth at low-water springs of 14 ft. for half the width of the channel, and a minimum depth of 8 ft. for the other half, the total width of the river there, from bank to bank, being only 410 ft. It was not till 1880 that the removal of the rock, so as to give a uniform depth of 20 ft. at low-water springs, over every portion of the channel, was commenced by Colonel Beaumont with his diamond drills. In addition to the novelty of using diamond drills, there was the further novelty that the holes were bored, charged and exploded from a floating barge without the aid of divers, a mode of blasting subaqueous rock which had never before been adopted.

The boring was done in longitudinal belts, in sections 40 ft. long. The holes were located in five rows, 2½ ft. apart transversely, and 5 ft. apart longitudinally, so that the holes in alternate rows would be opposite one another. Eight holes longitudinally were bored simultaneously, then charged and blasted, and the other four rows dealt with in the same way. When all the five rows in the section had been bored, charged and blasted, the boring barge was shifted up stream and operations commenced on the next 40-ft. long section, and an ordinary, but powerful, single ladder, small bucket dredger following, lifted the broken rock, and left an open face for the next belt of holes.

It was early found that where the depth of hole was more than 10 ft., the rock was not sufficiently disintegrated to enable the dredger to clear it freely away to the bottom of the holes, and the deeper portions of the rock were therefore taken in two depths, or breaks, the first depth being bored to 17 ft. at low water, blasted and dredged.

The longitudinal belts of holes were continued from the south side outward to the middle of the river, until the whole ground in the southern half was cleared away to 20 ft. at low water, the whole up-and-down traffic being meantime confined to the north half of the river. The whole traffic was then diverted from the north into the new south channel, which was marked by three of Pintsch's compressed gas-lit buoys, capable of burning three months continuously. The operations were then continued northward until the whole depth of the river-bed was cleared to 20 ft.

The explosives used were dynamite, blasting gelatine, tonite and potentite. Dynamite was found most satisfactory. Blasting gelatine

proved the most powerful explosive, but, when frozen, was more dangerous to handle and more difficult to explode thoroughly. Tonite and potentite were found to be less powerful than dynamite, and failed to explode unless kept quite dry.

Two horizontal engines on the deck of the boring barge, supplied with steam from two boilers, drove the eight drills by a main shaft, which extended the whole length of the barge. The diamond boring tool was a steel annular ring, $2\frac{1}{4}$ ins. diameter and $\frac{1}{2}$ in. hick, studded with diamonds overlapping one another. This annular ring or crown was screwed on to the bottom of the boring rod, which, in suitable lengths, was carried inside an iron guide tube extending down to the bottom of the river-bed; the rod was connected at the top to a drill bar suspended from an iron diagonal framework on the barge. Rotary motion was given to the drills by means of phosphor bronze bevel wheels, working in a frame and driven from the main shaft on deck by an ingenious arrangement of ropes and loose pulleys which allowed for any lateral or vertical movement of the drill caused by rough weather, the rise and fall of the tide, and the ranging of the barge through the suction of passing steamers. The drill bar was driven at the rate of 400 revolutions per minute; and during the whole time that the boring was proceeding, water, at a pressure of 40 lbs. per square inch, was forced down through the hollow boring rod, to wash out the detritus and keep the face of the diamond crown cool. The pressure on the drill was applied by means of counterbalance weights, varied according to the hardness of the rock bored. In the hard blue whinstone, the boring of the holes of $2\frac{1}{4}$ ins. diameter proceeded at the rate of 2 ft. per hour, and 5 ft. per hour in softer stone.

When the necessary depth of hole was bored, which was ascertained by sounding the hole and comparing the depth with that on the tide gauge adjoining the works, the drill rods were withdrawn, and the dynamite charges lowered through the guide tubes into the bottom of the holes and the tubes withdrawn. The dynamite charges were fitted with detonators and primers, and attached to each charge were electric cables, which were led up to the surface of the water. All the charges were then connected, and the shot-hole wires at either end were attached to a main cable, which was carried to the positive and negative poles of a Siemen's high-tension electric

exploder. The barge was then withdrawn about 60 ft. from the place of the explosion, and the row of eight holes was fired simultaneously, resulting in the displacement of something like 100 tons of rock, the only disturbance being a slight upheaval of water. The greatest amount lifted by the dredger in one day was 280 tons. A diving bell afterwards went over the ground and removed any large stones that had been left by the dredger.

More readily to convey an idea of the amount of labor involved in the removal of the rock, it may be stated that something like 16 000 holes were bored, equal to about 90 000 lin. ft. About 110 000 tons of whinstone and boulder clay were dredged. About 76 000 lbs. of dynamite and other explosives were used without loss of life or damage to limb, and were exploded by means of about 35 miles of electric cable and shot-hole wire. The cost from first to last was £70 000. Operations were carried on in all weathers, fair and foul, without interfering in any way with the continuous day and night traffic of the river; this, during the fully five years over which the work extended, was confined to the one or other half of the channel, and amounted to 180 000 vessels with a tonnage of 33 000 000 tons, and included the largest steamers then afloat, such as the *City of Rome*, the *Etruria*, and the Russian ironclad, *Peter the Great*.

The dredging plant of the Clyde Trustees consists of five steam dredgers, from 40 to 90 H. P. nominal (the latest addition, already referred to, being a steel hull, single traversing ladder, twin-screw propelled, electric-lighted dredger, 200 ft. long by 37 ft. broad by 12½ ft. deep, with a mean draft of 8 ft., cutting its own floatation); one tug steamer, two diving bells, one of them wrought entirely by steam; one floating steam 10-ton digger, and 18 steam hopper barges from 35 to 160 H. P. nominal. The latest two of the barges, also previously mentioned, have steel hulls, twin screws driven by triple-expansion engines, are each 200 ft. long by 34 ft. broad and 15½ ft. deep, and have a mean draft of 12½ ft. and a speed of 10 knots per hour when loaded.

The lighting of the channel of the Clyde between Glasgow and Port Glasgow is by three light-towers, at Dalmuir, Rashilee, and Donald's Quay, respectively, all above Bowling; by a beacon light at Longhaugh Point, one mile below Bowling, and by Dumbuck Lighthouse, about two miles below Bowling; by Garmoyle Lightship, one

mile below Dumbarton Castle; by Cardross Light, one mile above the Clyde Trustees' boundary at Port Glasgow; and by seven lighted buoys on the south side of the channel, between Dumbarton and Port Glasgow, the whole being lit by Pintsch's gas. The Clyde from Port Glasgow to the sea is lighted by the Clyde Lighthouses' Trust, under whose care the Estuary is to the Cumbrae Heads, 22 miles below Greenock.

In 1867 the Trustees erected works on the north bank of the river at Dalmuir, 8 miles below Glasgow, embracing slipway, engine and boiler works, for the prompt and efficient repair of their ever-increasing dredging and other floating plant.

2. Progress of the Harbour.

Three hundred years ago it could not have entered into the mind of the most sanguine and far-seeing citizen of Glasgow that this city, founded by St. Kentigern or St. Mungo, in A. D. 560, would ever become one of the leading ports of Great Britain; situated as it was on a shallow, sand-choked stream, upwards of 20 miles from deep water at Greenock, and its usual port, Irvine, in Ayrshire, 29½ miles by land from Glasgow, from which merchandise was conveyed to and fro by lighters and pack horses.

The magistrates of Glasgow, however, with that doggedness characteristic of Scotchmen, determined to have a port nearer home, and in 1658 made overtures to the magistrates of Dumbarton to purchase ground for an extensive harbour there; but these were declined on the ground that the great influx of mariners and others would raise the price of provisions on the inhabitants; they therefore, in 1662, purchased 13 acres at Newark, on which they afterwards laid out the town of Port Glasgow, built harbours, and constructed from the design of James Watt the first graving dock in Scotland, recently enlarged.

While thus fostering Port Glasgow, they still hankered after accommodation for ships at Glasgow, and in 1688 built a quay at the Broomielaw there at the cost of £1 666 13s. 4d.

In 1755 Smeaton recommended that in order to secure 4½ ft. of water at all times up to this quay, a dam be put across the river four miles below Glasgow with a lock 18 ft. in the clear, to take in a vessel 70 ft. long, or to let pass a sloop or brig of above 100 tons when there was water in the river to admit it.

The extension of the harbour synchronized with the deepening of the river, so that, while in 1800 the quayage was only 382 yds. long, and the water area of the harbour only four acres, the length of the quayage is now 11 056⅓ yds., or 6 miles 496⅓ yds., and the water area 160½ acres; fully one-half of the latter and of the total quayage having been added since the author became engineer to the Trustees.

The extension was from Glasgow Bridge downwards. Until 1865 the sides of the river afforded sufficient ground for the extension of the quayage. The first dock, called Kingston Dock, having 5⅓ acres of water space and 830 lin. yds. of quayage, was opened in 1867. The second dock, by special permission of Her Majesty, named the Queen's Dock, having 33¾ acres of water area and 3 334 yds. of quayage, with 20 ft. depth of water in front at low tide—spring tides—was opened in 1880. Both docks are tidal; and a third tidal dock which will be briefly described later on is in progress.

The early quays of the harbour were of stone, founded not much under the level of low water. Subsequently, as the deepening of the river progressed, bearing and sheet piling of round home timber were introduced, followed, as the deepening went on, by wooden wharfing of squared red pine timber, and quay walls carried on red pine bearing piles and sheet piles.

The deepening of the harbour and the lowering of low-water level, especially within the last 20 years, has injuriously affected the foundations of the quay walls, built even as late as 35 years ago; but by close sheeting in front of the walls, with creosoted pitch pine piles varying in length from 30 to 45 ft. by 12 ins. thick, driven in bays of three and four piles each and tied back at intervals with 2½-in. tie rods to heavy blocks of concrete masonry—the walls, built 70 and more years ago, have been kept up and made as suitable for the vessels of to-day as they were for the vessels of the period at which they were erected.

In 1870 the author, to meet the increasing depth demanded by the ships frequenting the port, and to secure a permanency which quay walls on bearing and sheet piles did not afford, adopted for the substructure of the quay walls a system of single brick cylinders 12-ft. external diameter, tongued and grooved into each other, filled with concrete, and of brick coped with granite for the superstructure; followed two years afterwards by triple groups of Portland cement concrete cylinders, 9 ft. external diameter, filled with concrete for the

substructure, and for the superstructure concrete rubble faced with dressed freestone ashlar and coped with granite. In recent years he has altered the facing of such walls to concrete ashlar.

As the details of this form of structure may be new to American engineers, the author will give a short description of the Queen's Dock just referred to.

The plan of the harbour, which accompanies this paper, shews the dock, which comprises three basins—the north basin, 1 866 ft. long by 270 ft. wide; the south basin, 1 647 ft. long by 230 ft. wide, with a quay between them, 195 ft. broad; and an outer basin, 695 ft. wide at its widest part by 1 000 ft. long. As already stated, the dock is tidal and is approached by an entrance 100 ft. wide, which is crossed by a swing bridge constructed by Sir William Armstrong & Co.

There are four coaling cranes to lift 20 tons each on the north quay of dock, all of which, together with the swing bridge—which is designed to carry 60 tons of a rolling load on any part of its roadway—are wrought by hydraulic power.

Before proceeding with the construction of the dock, it was necessary to learn by boring the character of the ground in which the walls were to be placed. One hundred and twenty-three borings were made for this purpose along the lines of the quay walls, and it was ascertained that the material, except along a portion of the north wall, where rock was sufficiently near the surface, and at the northwest corner, where boulder clay was found, was the worst possible in which to construct in the usual manner such works, consisting, as it does, of water-bearing gravel and sand, interspersed with pockets of mud.

Owing to the enormous quantity of water, the walls could not be constructed at a reasonable cost by excavating trenches to the required depth, except where the rock was sufficiently near the surface, or in boulder clay. The north quay wall of the dock, so far as founded on boulder clay, and that is for about 1 297 ft. of its whole length of 2 951 ft., is of the usual description, the only difference being that concrete founds, 2 ft. 6 ins. thick, were used in place of freestone blocks; and rubble set in Portland cement, a much superior mode of construction, was employed for the backing, instead of rubble built with ordinary mortar. Where the bottom consisted of strong coarse gravel or rock, liquid concrete was substituted for the solid concrete founds, by which means all the hollows in the surface of the rock were thoroughly

filled and an even and fair surface obtained on which to commence the building of the wall.

For all the other walls, except at two or three places where pockets of clay were encountered and piling was used and for the seat for the swing bridge, concrete cylinders were adopted for the substructure.

The cylinders carrying the quay walls are triple. They were made in rings, 2 ft. 6 ins. deep by 1 ft. 11 ins. thick, in movable wooden moulds on a platform. The concrete consisted of 5 of gravel, or broken stones and sharp sand, to 1 of Portland cement of the strongest description, mixed together by steam-power in a mixer designed for the purpose, water being added to bring the mass to a plastic state. To facilitate lifting, the rings were divided into three and four pieces alternately, so as to break bond when built into the cylinders. The dividing of the rings was very simply effected; malleable iron division plates $\frac{3}{8}$ in. thick were placed across the wooden moulds in the positions required before the concrete was filled into them; the concrete was then put in and well punned with rammers weighing 25 lbs., so as to secure homogeneity and a smooth surface. Twelve hours afterwards the division plates were withdrawn, and two days thereafter the wooden moulds; and in periods varying from nine days in the hot weather of summer to three weeks in the rains of winter, the rings were ready for removal and building. The contents of one ring complete were 10½ cu. yds., and the weight 18 tons, the heaviest portion weighing about 6 tons.

The cylinders were each 11 rings, or 27 ft. 6 ins. in height; the bottom ring, differing from the others, was called a "corbelled" ring, because it was made less in thickness at the bottom to fit into a cast-iron shoe, and tapered inwards to the full thickness of 1 ft. 11 ins. The shoe was 2 ft. deep of 1-in. metal, and of the same external size and shape as the rings, the underside of the bottom ring resting on a shelf in the shoe 6 ins. below the top edge of the shoe. This shelf was formed of an inner ring of cast iron 1 in. thick, projecting at the top 12 ins. inwards from the inside of the outer side of the shoe, and tapering outwards to the bottom of the shoe, where it joined the outer ring, thus forming a cutting edge to the shoe, the wedge-shaped space between the outer and inner ring being filled with concrete.

The shoe is only under the outward circumference of the "corbelled" ring, the inner parts of the ring being unshod. The shoe

weighed about 4 tons 10 cwts., and for convenience in placing in the trench was made in six parts and bolted together.

In proceeding with the construction of the substructure, a trench was cut on the line of the quay wall; the bottom of the trench was about 12 ins. below low-water level, where it was made 21 ft. wide, the sides sloping upwards with a batter of $1\frac{1}{2}$ horizontal to 1 perpendicular, and the necessary staging was erected to carry the traveling cranes and digging apparatus. On the bottom of this trench the shoes were placed exactly in the line of the quay wall, and the space between the outer and inner rings of the shoe was filled up with concrete, as already explained. The "corbelled" ring was placed on the shelf in the shoe, and bolted to it by 13 $1\frac{1}{4}$-in. bolts, a malleable iron ring 5 ins. by $\frac{1}{2}$ in. thick being sunk into the "corbelled" ring on the top, the places for this ring, and for the bolts passing through the concrete ring, having been made in the moulding of the latter. The remaining 10 rings, forming a triple group of cylinders, were set, one on top of the other, in Portland cement, in three and four pieces alternately. The cylinders were placed in the trench so as to dovetail into each other, one cylinder in front and two behind, and two in front and one behind, alternately. The sides of the groups, where they pressed against each other, were flattened for a length of 5 ft., so as to ensure a good bearing.

When the building-up of the rings forming a group of cylinders was completed, the sand and gravel were dug out simultaneously from within each of the three cylinders by means of excavators specially designed for the purpose. From 300 to 450 tons of cast-iron weights, of the same shape as the rings, were generally required to force each group of cylinders down the required depth of 48 ft. 6 ins. below the cope level of quay, the tops of the cylinders finishing 9 ins. below low-water level. The average rate of sinking was about 12 ins. per hour. In good working sand as much as 3 ft. per hour was, however, attained. When the group had been sunk, it was cleaned out by means of the excavators to the level of the bottom of the shoe, and each cylinder was then filled to the top with Portland cement concrete, and on this foundation the quay wall is built.

The walls are of concrete rubble, many of the stones weighing from 2 to 3 tons each, and faced with freestone ashlar in courses ranging from 18 to 15 ins. in thickness, the stones being not less than

4 ft. long by 2 ft. broad on the beds, and the headers not more than 10 ft. apart, centers. The cope is of granite, 3 ft. 6 ins. broad by 17 ins. thick, in lengths of not less than 4 ft.; and the mooring paals, or bollards, which are 32 ft. apart, centers, are built into the wall immediately behind the cope.

The swing bridge across the entrance to the dock rests on a foundation probably unique in the annals of swing bridges, viz., on a group of concrete cylinders, 12 in number, each 9 ft. in external diameter, 29 ft. in depth by 23 ins. thick, resting on cast-iron shoes, similar to those described for the quay-wall foundations. The cylinders were sunk in the manner already described, and after they and the interstices between them were properly cleaned out, all the voids were filled to the top with concrete, chock piles being driven where required. On the center of the rectangular area, 36 ft. 4 ins. by 27 ft. 3 ins. by 29 ft. deep, thus formed, a stepped ashlar pier 16 ft. square at the bottom and 10 ft. square at the top by 7 ft. high was erected, which carries a block of granite 7 ft. square by 3 ft. 6 ins. deep, on which the center lifting press rests. The pier is surrounded by concrete rubble, the whole forming a mass of masonry 36 ft. 6 ins. by 32 ft. 6 ins. by 10 ft. 6 ins. high, to the level of the floor of the bridge press chamber. The center pier sustains a weight of 800 tons.

Considerable difficulty was experienced in securing stable foundations for the hydraulic rams for working the bridge and for the capstans and side walls of the bridge pit, the ground being loose and insecure where these had to be placed. Single concrete cylinders placed apart, and spanned between by brick arches, overcame the difficulty.

The bridge is 181 ft. 6 ins. long by 40 ft. 6 ins. wide, the length overhanging the center of the center press and partly spanning the 100-ft. opening being 126 ft. 6 ins.

The swing bridge and hydraulic machinery have been in daily use since September 18th, 1877, when the dock was formally opened by the admission into it of the Anchor Line Steamship *Victoria*, 369½ ft. long by 40 ft. broad, 2 081 tons register.

The coaling cranes are capable of lifting 20 tons. They are placed on stone seats, the granite tops of which are 8 ft. above the level of the quay, and 21 ft. 6 ins. square; the lifting chains have a sweep of 29 ft. 9 ins., and, when at right angles to the face of the quay, project 19 ft. 9 ins. beyond the water face of seat; the lifts of the chains are 20 ft.

In addition to their employment in the shipment of coals, they are also adapted to the loading and unloading of machinery to their maximum lifting power.

The sheds are 60 ft. wide by 15 ft. high to the underside of the runbeams, and 27 ft. to the ridge of the roof; the back walls are of brick, 19 ins. thick, with freestone base course, cope and door openings; the roofs are of iron, and the fronts are closed their entire length, with sliding gates of timber. The cost per linear foot of shed at present prices is £10 10s.

The cost of the quay walls per linear yard including the excavation for trench below level of cope, was:

	£	s.	d.
Let in August, 1872:			
Quay walls on cylinders	154	2	0
Quay wall on sheet and bearing piles	144	8	0
Ordinary quay wall founded on boulder clay	116	5	0
Quay walls on piles and concrete, substituted for cylinders	172	0	0
Let in April, 1876:			
Quay wall founded on boulder clay	101	7	6
Quay wall on cylinders	139	4	0
Let in November, 1876:			
Quay walls on cylinders	129	12	8
" founded on rock	101	6	8

The total cost of the dock when fully equipped was £825 000, exclusive of land.

The following particulars connected with the dock may possibly be of some interest:

Excavation for walls above formation level	255 871	cu. yds.
Excavation in wall trenches	494 764	"
Excavation in sinking cylinders	126 407	"
Concrete in cylinder rings	1 800 203	cu. ft.
Concrete in filling of cylinders	1 313 010	"
Gravel filling of cylinders	99 495	"

Number of cylinders—triple	607
" twin	1
" single	20
Total	628

Total length of cylinders, 17 085 ft., or 3 miles 415 yds.

Ashlar masonry	747 223	cu. ft.
Rubble and concrete masonry	2 511 919	"

The quay walls are founded as follows:

Upon concrete cylinders	2 813	lin. yds.
Upon boulder clay	479⅔	"
Upon rock	210⅓	"
Upon hard gravel	122	"
Partly upon rock and partly upon boulder clay overlying rock	12½	"
Upon timber piling and concrete	56½	"
Timber wharf at entrance	134	"
Total	3 828	"

or 2 miles 308 yds.

The total quantity dredged in connection with the formation of the dock was 2 855 000 cu. yds.

The first of the ground acquired for the dock was bought in 1843 at 6s. 6d. per square yard, and the last in 1872 at 35s. Since the latter date, ground in the immediate vicinity, but not so favorably situated, has changed hands at 65s. per square yard.

The demands still continuing for increased quay accommodation, notwithstanding the large addition made to the harbour by the construction of the Queen's Dock, the Trustees nine years ago got powers from Parliament to construct another dock on the south side of the river. This is shown on the plan of the harbour already referred to, and comprises a canting basin and three berthing basins.

The entrance is completed, and the north basin nearly so, and a two-story shed, 70 ft. wide, is being erected on the north quay of that basin. The depth of the canting basin is to be 28 ft., of the north basin 20 ft., and of the center and south basins 25 ft. at low water, spring tides.

The substructure of the quay walls consists of a row of 9-ft. diameter triple concrete cylinders, except the walls of canting basin, which, in consequence of the additional depth of that basin, have a single row of 9-ft. diameter twin cylinders behind the row of triple cylinders, and the superstructure of all the walls consists of concrete rubble faced with concrete ashlar.

The thickness of the superstructure of the walls of the north basin, and of the center basin so far as constructed, is 16 ft. at bottom (on the top of the cylinders), and 6 ft. 6 ins. at top. Those of the canting basins are 26 ft. at bottom and 9 ft. 6 ins. at top. All are tied back at from 50 to 70 ft. intervals by 2½-in. tie rods to blocks of concrete masonry 12 ft. long by 8 ft. deep by 6 ft. thick. The whole of the work is being executed administratively, that is, without the aid of contractors, the iron shoes, all stones, including dressed granite cope, and other granite work ready for building, cement, timber, etc., being contracted for.

The cost of the walls of north basin was £80 per linear yard; of the walls of center basin, so far as constructed, £90 per linear yard; and of the walls of canting basin, so far as constructed, £120 per linear yard.

To enable the dock works to be gone on with, the Renfrew Road, the only thoroughfare between Glasgow and the great ship-building center of Govan and the Burgh of Renfrew, 60 ft. wide, had to be diverted for 1 575 lin. yds., and a new system of main sewers laid down for the populous district which surrounds the docks.

The river side and dock quays are well equipped with everything necessary for the speedy loading and unloading of vessels, including 5¾ miles of harbour railway on the north side, and 3 miles on the south side, connecting with the whole railway system of the Kingdom.

The Clyde Trustees have no warehouses, but have 30 acres of sheds for the accommodation and protection of goods. Unlike dock companies, the Trustees do not load and unload goods; these duties, with their consequent profits, are left to the ship-owners to perform. They, however, by means of 42 steam and hydraulic cranes ranging in lifting power from 30 cwt. to 75 tons, load coals and heavy machinery, discharge ore, mast vessels, and place boilers and engines on board steamers built on the river banks and in the neighbourhood; and there is now in course of erection in the harbour to meet the ever-increasing weight of marine boilers, a pillar crane, to be tested to 150 tons, of the following character and leading dimensions: the weights to be raised with a steel wire rope to a height of 60 ft. above the top of the crane seat from a depth of 20 ft. below the quay level, or a total lift of 100 ft. Its radius or sweep to be 65 ft., and to project 45 ft. beyond the face of the seat. The jib, a double steel tube, well braced, to be 90 ft. long, and 3 ft. 3 ins. in diameter at the center of each tube. Its weight, including stays, will be 45 tons.

The diameter of rope drum, 5 ft. 2 ins.; length, 10 ft.; weight, 10½ tons. Diameter of cast-steel roller path, 33 ft.; weight, 12 tons. In the live roller ring, 75 cast-steel rollers of a maximum diameter of 14 ins., weighing in all 10½ tons.

The washer plates for holding-down bolts, six in number, to be 6 ft. square, and their total weight 13 tons. The six holding-down bolts to be each 38¾ ft. in length by 5 ins. in diameter, and weigh 8 tons.

The steel center pillar to be 17 ins. in diameter, and the weight, 6 tons. The crane-framing to be 27½ ft. in height, and to weigh 50 tons, and the boiler to be 14 ft. high by 6 ft. in diameter, and to weigh 6 tons. The crane to have two separate lifts, 130 and 20 tons. The steel-wire rope for the former lift to be 2½ ins. in diameter, and 1 100 ft. long; and for the 20-ton lift, 1¼ in. in diameter and 370 ft. long. The main block with four pulleys to be 12 × 7 × 3 ft., and to weigh about 6 tons. The crane will be balanced by 100 tons of iron and steel punchings in a ballast-box.

There are to be two speeds for heavy lifts, 2 ft. per minute for 130 tons, and 4½ ft. per minute for 60 tons; and a separate engine for two speeds for loads up to 20 tons, viz., 12 ft. per minute for 20 tons, and 30 ft. per minute for 8 tons. The revolving to be performed by a separate engine with two speeds—a revolution in 6 minutes for 130 tons, and 3¼ minutes for 60 tons.

A description of the seat on which the crane is being erected may be of interest. Its site is shown on the plan on Finnieston Quay, north side of harbour.

To admit of its erection, a portion of the quay wall forming the north line of the river had to be taken down before proceeding with the substructure. This consists of three front groups of triple concrete cylinders, with four single concrete cylinders close behind them, and three groups of triple concrete cylinders close behind the latter, all of 9 ft. external and 5 ft. 9½ ins. internal diameter, resting on cast-iron shoes. The front groups were sunk to the average depth of 60 ft. 8 ins., the four single cylinders to 59 ft., and the three back groups to 56½ ft., below the level of cope of quay wall, and all filled with Portland cement concrete. The tops of the front cylinders are 25 ft., and the single and back cylinders 22½ ft., below the level of cope of quay wall; and from these levels the superstructure of the seat, which is 40 ft. square, rises to 20 ft. above the cope level of quay wall, and consists

of concrete rubble hearting with granite corners and cope, faced in front to the level of the underside of cope of the quay wall with redressed freestone ashlar. This ashlar was from the portion of the quay wall removed to permit of the erection of seat. The superstructure at back and sides to the level of the quay was faced with heavy rubble, and thence to the underside of the cope of seat with concrete ashlar.

Several of the largest ship-builders and marine engineers, such as Messrs. A. & J. Inglis, the Fairfield Ship-building & Engineering Company, Limited; Alexander Stephen & Sons, and James & George Thomson, put boilers, engines, etc., on board by means of shears or cranes in their own yards.

Berths are set aside for special trades, such as coal, lime, timber, river passenger steamers and cattle, and fully a half of the total quayage of 11 056½ yds. is allocated to the leading lines of steamers trading to outports of Scotland, England and Ireland, to the leading Continental ports of Europe, to the British Colonies, and to America, Canada, the East and West Indies, Africa, etc.

The Trustees permit ship-owners having allocated berths to place steam cranes on the breasts of the quays, and there are at present 32 of these in use, ranging from 30 cwts. to 30 tons in lifting power.

In 1856 a private ship-building firm on the confines of the harbour built a graving dock 500 ft. long in connection with their yard, and it was not until 1875 that the first public graving dock, 565 ft. long by 22 ft. 10 ins. on the sill at high water, spring tides, was completed by the Clyde Trustees at a cost, exclusive of land, of £134 800. Another, 575 ft. long by 52 ft. 4 ins. wide at bottom, 92 ft. wide at top, with the same depth on the sill as the last named, constructed by and from the designs of the author without the aid of contractors, as has been all the quayage of the harbour for the last 10 years, was opened in 1886 at a cost, exclusive of land, of £108 200.

The wing walls and apron of the latter are carried on triple concrete cylinders, 9 ft. diameter, sunk 24 ft. into the ground and filled with concrete, their tops being 3 ft. below the level of top of sill at the entrance. One of these triple cylinders was used as a well for a 13-in. centrifugal pump, which was required to keep under the large amount of water flowing from the gravel strata in which the excavation for the dock had to be carried.

Into this well were led three lines of 9-in. open-jointed, spigot and

faucet pipes; these were of cast iron under the sills, and fire clay thence to the upper end of the dock. These pipes were laid under the foundations of the floor on an inclination of about 1 in 300, with branches from each as required, to give free passage to every spring of water that was met with. To prevent them from choking with sand, a small wire rope with wire brush attached was carried through each pipe from the well to the upper end, as the work of excavation proceeded from the entrance to the head of dock, and they were quite successfully cleared by this means.

The pipes were bedded in, and covered to the depth of 18 ins. with clean riddled gravel, which kept the ground well dried for the laying of the bottom bed of concrete forming the lowest section of the foundations of floor and side walls. On this concrete bed, which is 12 ins. thick at the center, and 3 ft. 2 ins. at the sides, a brick-in-cement invert 4 ft. 2 ins. thick was laid to the radius of 120 ft., surmounted by a bed of concrete 4 ft. 5 ins. thick in the center, tailing out to 12 ins. on each side with a camber of 6 ins. on the upper surface. On this was laid the flooring of the dock consisting of nidged granite blocks 6 ins. thick, set in and grouted with cement. The floor at the center is 12 ins. below the sill, and is level longitudinally.

The limited width of the site of the dock prevented the excavation being taken out to the usual width on the top, and the desire to get the dock as wide and long as the ground would admit of necessitated the driving, along both sides and round the head, of pitch pine sheet piling, 28 ft. long by 9 ins. thick on the sides, and 12 ins. thick round the head of dock, in four-pile bays, with slip tongues, 16 ft. of the length being into the undisturbed bottom.

In front of this sheet piling, brickwork was carried up from the invert over the top of the piling, and the ground behind the piling was cut away for a breadth of 7 ft. 6 ins. and a depth of 6 ft. and filled with concrete, on which the outer side walls, 37 ins. thick at bottom and 18 ins. at top, plumb at back and stepped inside, were built, the whole being carefully pointed outside to secure water-tightness.

Inside of these walls, the whole body of the dock is of concrete, except the side walls of the entrance, the stairs, timber slides, the top altar course and cope, which are of granite. All the other altar courses, 17 in number, are of granolithic, 14 ins. on the tread and 18½ ins. rise, except the bottom course, which is 30 ins. average rise.

The concrete of the sides of the dock was put in between movable frames, roughly stepped to receive the granolithic altar courses, which were moulded on a platform on the working ground, and when thoroughly dry, built in position like ashlar, except the bottom altar course, which was made *in situ* in 8-ft. lengths and in alternate blocks, to allow of setting and shrinkage.

The floor of the caisson chamber is a brick-in-cement invert, with granite stones and cast-iron blocks alternately, for carrying the rails upon which the caisson travels, the cast-iron blocks being cored out for the drainage of the mud from the rails.

The side and end walls of the chamber are of brick, with rectangular voids filled with concrete, and having a freestone string course on each side for the hauling-chain path.

The caisson chamber is covered over with Lindsay's patent steel trough decking, having the troughs filled up with concrete, and a layer of 4 ins. thick over the whole, and causewayed over to form a part of the roadway.

The semi-circular head of the dock is formed of brick in cement, stepped at back, with rectangular voids filled with concrete and faced with moulded granolithic-faced concrete ashlar, battered on the face to 1 in. per foot, in courses 18 ins. deep, chamfered on top and bottom edges, the stretchers being 4 ft. long by 1 ft. 9 ins. broad on bed, and the headers 3 ft. 6 ins. long by 2 ft. broad.

There are two stairs with two stair approaches to each, and four timber slides on each side of the dock. The stairs are 4 ft. 6 ins. wide, with landings about half way down. Each landing is approached from the surface by two stairs parallel with the dock and entering from opposite directions; the steps of stairs are 12 ins. broad and 6½ ins. rise.

The caisson for closing the entrance is of iron, rectangular in shape, as was first used in 1850 to close the lock entrance at Keyham ; with folding roadway and handrails, similar to the caisson with folding handrails and lowering and raising roadway deck adopted in 1867 by Sir Andrew Clarke, R. E., to close the entrance to the Royal Somerset Graving Dock, Malta ; but instead of sliding, as at Malta, it is moved by rollers fixed under it, which run on broad iron rails laid on each side of the floor of the caisson chamber.

The caisson has a water-tight deck about half way between the bottom and top, and is ballasted with 180 tons of concrete ballast, 60 tons of

which is portable, being in 12-in. cubes which can be lifted out to enable the caisson to be floated out of its recess if required.

The whole of the cement used in the construction of the dock was the best quality of Portland. The proportions of gravel and broken stone and cement for the concrete were as follows : for the making of the triple cylinders, 5 to 1 ; floor and sides of dock and ballasting of caisson, 6 to 1, the concrete on the sides being supplemented by a plentiful supply of rubble ; for the covering of the caisson chamber, 8 to 1 ; and for the filling of the concrete cylinders, 9 to 1.

The gravel for the concrete was mostly got from the excavations, the remainder was Thames gravel brought round from London as ballast, and a considerable quantity of the rubble stone was from the blasting of Elderslie Rock, already referred to.

All the concrete was mixed by Jamieson's patent mixers, and the stones were broken by Hope's patent stone breaker.

The granolithic altars consist of 3 parts of crushed granite to 1 of cement, and the granolithic-faced ashlar of 6 ins. of granolithic of the same quality, the remainder of the blocks being 5 to 1 concrete. The mortar for building the brickwork was composed of 1 part of cement to $2\frac{1}{2}$ of sharp sand; and for pointing, 1 part of cement to 1 of sand. All the sand was obtained from the excavations for the dock.

The dock is emptied by the pumping engines of No. 1 dock through a 5 ft.-9 in. bore cast-iron pipe; but this pipe having been put in simultaneously with the construction of No. 1 dock, for the second dock to be 2 ft. 10 ins. less in depth, the last few inches of water above the floor in No. 2 dock has to be emptied by an auxiliary pump, a 10-in. centrifugal, by Messrs. Easton & Anderson, London, driven by a 16-H. P. nominal gas engine, by Messrs. Crossley Brothers, Manchester.

The caisson was made by Messrs. Hanna, Donald & Wilson, Paisley; the caisson hydraulic engine, which can also be worked by hand, is by Messrs. Tannet, Walker & Co., Leeds; and a new hydraulic pumping engine, for working the accumulator for the hydraulic power required for the hauling engine of No. 2 dock and the capstans and sluice valves of both docks, was supplied by Messrs. Fullarton, Hodgart & Barclay, Paisley. The sluices were furnished by Messrs. Easton & Anderson.

All the three engines are underground, in roomy, white-glazed brick-lined houses, the two former being roofed over at the surface by

rolled beams and concrete, and furnished with Gourlay's prismatic lenses for lighting.

The author has no information as to when ferry-boats commenced to ply across the harbour, but they have now become an important means of public communication between the north and the south sides of the city and suburbs. The Clyde Trustees have, at present, 10 cross-harbour passenger ferry steamers, from 6 to 7½ H. P. nominal, licensed to carry from 93 to 110 passengers, nine of them having fire engines on board, for the service of the four cross-ferries within the limits of the harbour and for the two across the river below the harbour at Meadowside and Whiteinch respectively; and two vehicular and passenger ferries combined, one at Finnieston, about the center of the harbour, and the other at Govan, the western boundary of the same.

The ferry at Govan has been in existence for many years, by a boat worked by hand-wheels up to 1867, and since then by steam. The first steamer was of 15 H. P. nominal, having a single cart and carriage way in the center, accommodating three horses and carts and 50 passengers, or 200 passengers alone, and wrought on one chain stretched across the bottom of the river.

A second steamer for Govan Ferry, designed by the author, commenced working in 1875. It is 20 H. P. nominal, has two cart and carriage ways, one on each side, the passengers being accommodated in the center; carries eight horses and carts, and 140 passengers, or 500 passengers alone, and is wrought on two chains across the river, one on the inside of each cart and carriage way.

A vehicular ferry steamer of peculiar construction, designed and built by Messrs. William Simons & Co., Renfrew, was put on to ply across the harbour at Finnieston two and a half years ago, its main feature being an elevating deck which is raised and lowered by bevel and worm gearing, so that at any state of the tide the deck is brought to the same level as the quay.

The vessel has four screws to give her great manœuvering facilities, is 80 ft. long, 44 ft. broad, depth amidships, 12 ft., and draft amidships when loaded, 9½ feet. The hull is built of steel and the decking of iron. It is divided by 13 bulkheads, five of them transverse.

The elevating deck, which is 78 ft. long by 32 ft. broad, when in its lowest position rests on the iron deck. Nineteen feet of the width is for vehicles, and 6 ft. 6 ins. on each side is reserved for passengers.

Vertical screws of forged steel, six in number, three on each side, 7 ins. in diameter, carry the elevating deck ; and are supported by six columns formed of two box girders, one on each side of each screw, 12 by 14 ins., channel section, placed 2 ft. apart, and on turning the screws by bevel gearing the elevating deck is moved. Each of the screws works in a manganese bronze casing, bolted between the two box girders forming each column, and placed so that the deck may rise 14 ft. The columns are held in position at top by longitudinal and transverse steel girders of I section, and to the sides of the vessel by similar girders; and on the top of the former, the wheelhouse, with steam steering gear is placed, with telegraphic communication to the engine-room.

The machinery for propelling the vessel and for operating the elevating deck is placed in one compartment in the center of the vessel under the iron deck, while at either side is a boiler. The boilers are horizontal tubular, 7 ft. in diameter by 7 ft. 6 ins. long, constructed of Siemens-Martin steel, for a working pressure of 150 lbs. to the square inch.

There are three horizontal triple-expansion engines, all of the same design and size. Cylinders, 9 ins., 14½ ins. and 24 ins. diameter, respectively, with a piston stroke of 18 ins. Two of the engines are placed athwartship, the one driving the line of shafting running fore and aft, and operating the port screws at both ends of vessel, while the other drives the shafting for the starboard screws. The third engine is placed between the two others, and lies with pistons working in a fore-and-aft plane, driving a line of shafting running athwartship and connected through spur and bevel wheels with two lines of fore-and-aft shafting of 4¼ ins. diameter wrought steel, geared on the respective sides to each of the vertical screws for moving the elevating deck.

The vessel accommodates 300 passengers and eight loaded carts with horses, or 700 passengers alone, and works across the river between a recess on the north side and two dolphins on the south side, and has proved a perfect success in every way.

The Trustees have also a rowboat ferry across the mouth of the Kelvin at Govan.

The Renfrew Burgh authorities maintain a steam vehicular ferry across the river at Renfrew, and Lord Blantyre one at Erskine.

The number of passengers conveyed across the river at the different ferries belonging to the Trustees for the year ended June 30th, 1892, was 9 054 429, and of vehicles 218 510, and the gross revenue derived therefrom amounted to £19 219 13s. 10d. The charge for crossing is one-half penny for each passenger, but 18 single-journey tickets are sold for sixpence.

In April, 1884, the Clyde Trustees established under the authority of Parliament a service of passenger steamers called *Cluthas*, from the word *Clutha*, the Gaelic name of the Clyde, to ply between Victoria Bridge, Glasgow and Whiteinch, a distance of 3½ miles. These steamers, now ten in number, are twin-screw, from 74 to 102 ft. long by 13 to 17 ft. beam, licensed to carry from 235 to 360 passengers, ply at 10-minute intervals between these points, and call at various intermediate stations on both sides of the harbour, at the fare of one penny for the whole distance. During the year ended June 30th, 1892, they carried 2 949 661 passengers, the gross revenue from which was £12 373 11s. 9d.

The total number of persons in the exclusive service of the Trust, including about 400 engaged at the new dock and other new works, is 1 598.

Having now given a somewhat detailed account of the conversion of the river into a navigable water-way, and of the progress of the harbour up to date, the question may be fairly put, What about the cost? The gross total expenditure from the year 1770 till June 30th, 1892, amounted to the very moderate sum of £13 641 301 5s. 0d. Included in that amount is—

£471 194 15s. 7d. for the general management, officers' salaries, etc.

£425 997 5s. 7d. for the ground annuals, and feu duties.

£299 174 8s. 1d. for taxes, and

£4 287 073 7s. 11d. for interest on borrowed money.

For complete details as to the total expenditure, see Appendix I.

The gross revenue from July, 1752, to June 30th, 1892, amounted to £8 890 279 7s. 5d. For details see Appendix II.

The total debt due by the Trust as at June 30th, 1892, was £4 843 228 8s. 0d.

To show the nature of the expenditure and revenue for a year, a detailed abstract of each of these, from the annual accounts of the Trust for 1892, is given in Appendices III and IV.

While in 1656, Commissioner Tucker stated that there were only 12 vessels belonging to the merchants of the port, three of 150 tons each, one of 140, two of 100, one of 50, three of 30, one of 15, and one of 12, none of which came up to the town, the Board of Trade statistics for 1891 show Glasgow to be the third largest ship-owning port of the Kingdom, with 1 576 vessels of an aggregate tonnage of 1 316 809, as compared with Liverpool with 2 307 vessels of 1 994 903 tons, and London with 2 685 vessels of 1 500 572 tons.

Glasgow, in regard to entrances and clearances of vessels to and from foreign countries and British possessions, stands sixth in the list of British ports with 2 303 vessels of 2 657 057 tons, being surpassed by London, Liverpool, Cardiff, the Tyne ports, and Hull, while in regard to the coasting traffic it stands fifth with 16 271 vessels of 3 110 211 tons.

Glasgow is the birthplace of the Allan Line, the Anchor Line, the City Line and the Clan Line, of first-class steamers, by which constant communication is kept up with Canada, the United States, Africa, and India ; while the famed Burns Line of mail steamers cross nightly to and from Belfast, in all sorts of weather, with such regularity that the town clocks of Greenock might be safely set by their arrival and departure. Aitken, Lilburn & Co.'s lines of sailing ships to Melbourne and Sydney leave nothing to be desired. Various other lines maintain frequent communication with other colonial and foreign ports, while the connections with the English, Irish and continental ports are numerous and regular. Nowhere can such a fleet of handsome and commodious river passenger steamers be seen as on the Clyde ; the names of many of them have become household words for all that is luxurious and comfortable in pleasure sailing.

The first commerce of Glasgow was the curing and exporting of salmon caught in the river, and the curing and exporting of herrings brought by wherries from the West Highlands. The union of England and Scotland, consummated March 25th, 1707, though violently opposed and leading to riots of a serious character, yet gave to the commerce of Glasgow its first great impetus. The opening up to Scotland of trade with the colonies led its merchants to go into shipowning on their own account instead of, as hitherto, chartering vessels from the port of Whitehaven and elsewhere in the Northwest of England, and ultimately gave them the largest share of the foreign export

trade and a monopoly of the tobacco trade of the Kingdom; so that, in the year 1772, out of 90 000 hogsheads of tobacco imported into Great Britain, Glasgow alone imported 49 000; and in the year preceding that of the American War of Independence, the imports into the Clyde were 57 143 hogsheads, the property of 42 merchants who realized princely fortunes.

The Declaration of Independence changed all this, and "fresh woods and pastures new" had to be sought for. Trade with the East and West Indies was opened up and cotton-spinning started. At this time the vast mineral deposits of the West of Scotland still lay many fathoms deep, waiting the genius of James Watt to supply the mighty power to bring them to the surface and to raise the strong blast to fuse them into use. The power-loom, introduced into Glasgow in 1773, and driven by a large Newfoundland dog, also waited his master-hand, which was at length so well applied that in 1846 the consumption of cotton in Scotland was 119 225 bales, the greater part being absorbed in Glasgow.

All this is now altered. Little tobacco is imported direct, and the consumption of cotton is much reduced; but in place of these, the imports of American and other produce in their infinite variety has largely increased. Glasgow has become a large distributing center for the Southwest of Scotland and the North of England, and trade in Spanish and other ores and in fruit has sprung up in recent years, which has more than made up for the loss of the tobacco, cotton and tea.

The mineral wealth of the district in coal, iron, lime, shale oil, etc., has also been largely developed; and the making and exporting of sugar machinery, locomotives and wrought-iron work has taken such deep root in Glasgow and neighbourhood that they will not easily be displaced. The Singer Sewing Machine Company, too, have, within the last few years, completed the erection of large sewing machine works on the north side of the Clyde, about 6 miles below Glasgow, which cover 46 acres of ground, and give employment to several thousands of men, women and children.

In no instance have river improvement works been attended with such beneficent results—commercial, industrial and social—as those of the Clyde, which has in recent years been indeed a gold-producing stream.

For the year ended June 30th, 1892, the chief exports from Glasgow Harbour were :

	Tons
Ale, beer and porter	44 639
Bale and box goods	143 964
Bricks	53 530
Coal	1 267 699
Coal tar	17 651
Coke	8 159
Confections	6 617
Earthenware	10 579
Gas coal cinders	7 815
Grain	15 908
" manufactured	49 656
Iron and steel:	
Bar, bolt, rod and sheet	100 496
Blooms	1 485
Boilers	2 178
Bolts, nuts, rivets and spikes	5 782
Bridgework, girders and roofing	7 189
Castings	44 986
Fencing	1 826
Fish plates	383
Galvanized	3 027
Gas and water pipes, cast	66 411
Ore	11 341
Pig-iron	144 626
Puddled iron	2 385
Rails	1 071
Railway sleepers, wrought	3 701
Railway and tramway plant and material	2 780
Scrap	33 457
Tubing	14 381
Tires and axles	692
Machinery and machines	64 890
Manure, chemical	26 701
Oil—Scottish shale	20 214
Oils—all other kinds	8 641

	Tons.
Pitch	32 509
Spirits of all kinds	29 638
Timber	16 272
Animals:	
Horses, ponies, mules and asses	1 425
Cattle	1 219
Sheep	13 990
Lambs	6 767

For the same year the chief imports were:

Bale and box goods	48 695
Cake feeding of all kinds	12 577
Cement	63 869
Chalk	9 059
Chrome ore	16 091
Clay, china and stone	34 273
Coal	5 171
Cotton seed	7 515
Dyewood	6 420
Fish	19 321
Fruit	39 646
Grain	362 960
" manufactured	206 012
Hay	13 491
Ice	12 892
Iron and steel:	
Bar, bolt, rod and sheet	4 965
Blooms	529
Ferro-manganese	1 675
Girders	1 796
Ore	485 167
Pig-iron	65 776
Rails	2 600
Scrap	16 774
Linseed	7 549

	Tons.
Nickel ore	22 577
Nitrate of soda	9 866
Oils of all kinds	24 851
Potatoes	6 614
Provisions:	
Bacon and hams	14 155
Beef, mutton and pork	14 063
Bread	126
Butter	7 597
Cheese	9 077
Lard	3 884
Meats, fresh	3 545
" preserved	5 779
Pyrites	52 662
Rice and rice flour	4 636
Rosin	9 654
Salt	19 837
Sand	19 189
Soap	4 087
Spirits of all kinds	13 454
Stones	27 331
Sugar	21 579
Timber	137 819
Tobacco	3 136
Treacle	5 275
Turpentine	3 794
Wines of all kinds	4 682
Yarn	4 679
Animals:	
Horses, ponies, mules and asses	5 970
Cattle	163 425
Sheep	44 313
Lambs	43 350

The total exports were 2 594 213 tons, and the total imports 2 302 604 tons.

3. Rise and Progress of Ship-Building on the River and its Tributaries.

Of the numerous industries that flourish on the banks of the busy Clyde, the palm must be given to ship-building and marine engineering. These, as much as its commerce, have spread its fame over every portion of the habitable globe; its floating palaces traverse every sea. The Clyde took the lead in introducing the steamboat to the Old World, which in the short space of 80 years, has revolutionized the carrying trade of the world, and brought about that commercial intercourse between nations which has so vastly increased the comfort and happiness of the whole human race. The application of James Watts' inventions to steam navigation by Patrick Miller, William Symington and Henry Bell, and the improvement of the Clyde, most singularly coincided, and the further development of both still go hand in hand.

But for the continuous deepening of the river, while there might possibly have been a *Comet*, there could have been no *Iona*, no *Columba*, no *Lord of the Isles*, no *Livadia*, with its 153-ft. beam, no *Umbria*, no *Etruria*, no *City of New York*, no *City of Paris*, no *Campania*, no *Lucania*, launched from its banks above Dumbarton. So far, however, as depth of water was concerned, ship-building was always possible at Dumbarton, Port Glasgow and Greenock.

By 1839, four firms had established ship-building yards at Glasgow within the limits of the harbour: Tod & Macgregor and Thomas Wingate & Co. on the south side, the latter of whom engined the *Sirius*, built at Leith in 1837, the first British steamer to cross the Atlantic, and Robert Napier and Barclay Curle & Co., on the north side. Some few years thereafter two additional yards were established on the north side and four on the south side. All the yards but one on the north side and all but three on the south side have been forced out of the harbour by the ground they occupied being absorbed for quay extension.

The first removal was in 1846, to the west bank of the Kelvin at its junction near the Clyde, and the others followed as necessity required, one to the south side of the river, and the others to the north side of the river at Whiteinch, opposite, a distance of 1½ miles below the Kelvin; and another, Messrs. James & George Thomson's, to Clydebank, on the north side of the river below Renfrew, where the twin-screws

City of New York and *City of Paris* were built and engined. About 30 years ago, a new yard was established on the east bank of the Kelvin, at its junction with the Clyde.

Fully 20 years ago, Messrs. John Elder & Co. established on the south side of the river perhaps the most extensive private ship-building yard and marine engine works in existence, at Fairfield, Govan, now the property of the Fairfield Engineering and Ship-building Company, Limited, where the twin-screws *Campania* and *Lucania* were built and engined. About 15 years ago another yard was laid out on the north bank of the river at Clydebank.

There are upwards of forty ship-building yards in what may be termed the Clyde district. One yard is at Rutherglen three miles above Glasgow Bridge, where have been built many of the beautiful steam yachts and pleasure steamers which ply on our English lakes, on our Scottish lochs and on foreign waters; one at Blackhill on the Monkland Canal, one at Kirkintilloch and three at Maryhill on the Forth and Clyde Canal, five within the limits of the harbour; one at Patrick, immediately below the limits; two at Govan, three at Whiteinch, two at Renfrew, two at Clydebank, four at Paisley, one at Bowling, five at Dumbarton, seven at Port Glasgow, four at Greenock, and the remainder at Fairlie, Ardrossan, Troon and Ayr.

Lloyd's Ship-building Returns give the total number and tonnage of vessels launched in the United Kingdom, and built abroad, during 1892, to be—

659 steamers, with a gross tonnage of.....	967 566	
392 sailing ships, of a gross tonnage of.....	390 479	
83 war ships, with a total displacement of.....	308 901	tons.

a total of 1 134 vessels and 1 666 946 tons, of which were built in the United Kingdom—

512 steamers, with a gross tonnage of.....	841 356	
169 sailing ships, with a gross tonnage of.....	268 594	
30 war ships, with a total displacement of.....	151 157	tons.

or a total of 711 vessels and 1 261 107 tons, the Clyde taking the lead with an output of—

133 steamers, with a gross tonnage of.....	140 350	
81 sailing ships, with a gross tonnage of.....	159 002	
3 war ships, with a total displacement of.....	22 826	tons.

or a total of 217 vessels and 322 178 tons.

The Tyne district is next with a total of 101 vessels of 219 936 tons, followed by the Wear with a total of 75 vessels of 186 440 tons, and Middlesboro', and Stockton-on-Tees with 46 vessels of 103 725 tons.

The first iron vessel built in Scotland was the *Vulcan*, by Thomas Wilson, at Faskine on the Monkland Canal, about 11 miles from Glasgow. It was launched on May 28th, 1818, and until within the last 20 years was engaged in carrying coal from the Forth and Clyde Canal to ports on the Clyde. To England, however, belongs the honor of launching, in 1821, the first iron steamer, the *Aaron Manby*, built at Horsley.

The first iron steamer built on the Clyde was the *Aglaia*, in 1827, for passenger traffic on Loch Eck; and the first to ply on the Clyde was the *Fairy Queen*, built at the Old Basin Foundry, Glasgow, about a mile and a half from the river, to which it was brought bodily and launched in 1831.

4. Short Description of Other Harbours on the River.

A description of these harbours, to do them justice, would require a separate paper, written by one with more local and special knowledge of them than the author possesses.

Renfrew.—About 5 miles below Glasgow Bridge is Renfrew. A royal burgh, its proximity to its great neighbour has over-shadowed it; from time to time its authorities have made laudable efforts to give it a harbour, but have, as yet, had to be content with an extension of the quayage on the town side of a burn called the Pudzeoch.

Paisley.—Next in order is Paisley, situate on the River Cart, about 3½ miles from the junction of that river with the Clyde, now a thriving thread-spinning, corn-flour-producing, shawl-manufacturing, ship-building and general engineering town. It allowed Glasgow to take the lead in river improvement and in former years got more than one Act of Parliament to deepen, straighten and widen its river without much good result. Under an act passed in 1885, the quayage at Paisley has been largely extended, and the river is being deepened to 18 ft. below high water of spring tides. Financial difficulties, however, have for the present stopped the completion of the work.

Bowling Harbour.—This harbour comes third, and is about 11 miles below Glasgow. It has a tidal basin of 12 acres, the joint property of the Clyde Trustees and the Caledonian Railway Company, used by the

latter in connection with the Forth and Clyde Canal of which they are owners, and by the former in the laying-up for the winter of the extensive fleet of passenger steamers plying in summer on the waters of the Clyde and adjoining lochs. Here, side by side, may be seen, dismantled and silent, the famous *Iona*, *Columba*, *Lord of the Isles*, and many other river steamers, which, during the summer months, are crowded with tourists from all parts of the world, who view with admiration the enchanting scenery of the Western Highlands.

Dumbarton.—The present authorities, inspired with much broader views on the harbour question than were their predecessors of 1658, in 1881 carried through Parliament a bill for the improvement of the River Leven, and the providing of increased quay accommodation; but beyond some deepening, not much has yet been done.

Port Glasgow.—The old harbours were acquired by the municipal authorities of this port in 1864, from the magistrates of Glasgow, on payment to the latter of 5s. per pound sterling on the amount of the debt on them. A considerable amount of iron ore is discharged there and sent to the various iron works in the west of Scotland.

The harbour accounts for the year ended June 30th, 1892, show a gross revenue of £4 813 3s. 6d., and a total expenditure of £4 599, of which £2 652 15s. were paid for interest on borrowed money. The total debt of the Trust is £71 262 11s. 3d.

Greenock.—Glasgow's greatest rival and ancient superior, and the birthplace of James Watt, a few years ago, through the enterprise of its leading men, engaged in harbour extension of an important character, chiefly in the construction of the James Watt Dock. This unfortunately led to a serious crippling of its harbour finances, in consequence of the shipping trade of Glasgow refraining from making use of the accommodation it afforded. The aid of Parliament had to be obtained to rearrange the harbour debt, and it is gratifying to be able to say that, by this rearrangement, and the gradual development of trade in the district, the financial position of the harbour is rapidly improving. The gross revenue for the year ended September 5th, 1892, was £64 667 16s. 6d., and the total debt £1 529 211 14s. 7d. The harbour has a total water area of 52 acres, and there are three public and two private graving docks.

The Board of Trade returns for 1891 show that 309 vessels, of 240 100 tons, belong to Greenock; that the entrances and clearances of

vessels to and from foreign countries and from British possessions were 529 vessels and 438 529 tons, and the coasting traffic 15 760 vessels of 2 950 434 tons.

Sugar importing and refining, timber importing, and ship-building and marine engineering, form the staple industries of the town; and the ship-builders and marine engineers higher up the river, find in the ship-builders and engineers of the town keen and often successful competitors in the obtaining of contracts.

The principal imports for the year ended September 5th, 1892, were—

Coal	11 585	tons.
Iron, ore	33 935	"
" pig	8 540	"
Lime	2 460	"
Sand	6 859	"
Sugar	149 667	"
Timber, pine and teak	101 568	loads.
" oak, elm, birch, etc.	17 608	"
" deals	12 037	"

And the principal exports were—

Coal	143 825	tons.
Iron, wrought	4 686	"
" pig	4 530	"
Manure	3 793	"
Sugar	84 795	"

The natural Clyde begins at Greenock, where the artificial Clyde terminates, and the panorama thence to the Atlantic is one of exquisite beauty, and must be seen to be fully appreciated; the serrated peaks of the Argyleshire Hills, rising in their sublimity towards heaven, on the north, the Island of Bute and the two Cumbraes guarding the entrance from the sea, while, still farther seaward, Goatfell in Arran rears its lofty head proudly to the sky, and away in the far distance, stands forth, lonely in its utter isolation, the "craggy ocean pyramid," Ailsa Craig.

The numerous watering places, with their infinite variety of architectural designs, close-shaven lawns and expanses of foliage, which fringe both sides of the estuary, in some places for miles contin-

ously; the innumerable white-winged yachts skimming its surface in all directions, the outward or inward bound Atlantic liner ploughing its way through the azure waters, the full-sailed Indiaman gliding slowly along, and ever and anon the swift passenger steamer, dashing from pier to pier, make during the summer months a scene which, once gazed upon, can never be forgot.

APPENDIX I.

CLYDE NAVIGATION.

ABSTRACT OF TOTAL EXPENDITURE FROM THE YEAR 1770 TO JUNE 30TH, 1892.

	£.	s.	d.
General management, officers' salaries, etc.....	471 194	15	7
General expenditure, repairs and upkeep of works, damage to fishings, etc.....	807 088	18	1
Extraordinary repairs, Parliamentary opposition, etc.....	53 593	3	0
Crane wages and repairs.....	137 946	17	9
Ferries, wages, and repairs of boats.....	298 018	17	1
Ground annuals and feu duties.....	425 997	5	7
Law and Parliamentary expenses.	96 676	13	8
Police.....	76 982	17	7
Rhones and planks for shipping	35 984	15	8
Water supply for vessels.....	47 167	9	6
Taxes	299 174	8	1
Lighthouses on river.....	16 369	16	9
Interest on borrowed money.....	4 287 073	7	11
Dredging in river and harbour. Repairs of machines, punts, etc., including new machines, tugboats, barges, punts and machinery....	1 731 571	14	0
Land purchased for enlargement of harbour...	1 229 353	16	4
Land purchased for widening river.....	178 289	11	6
New hall and offices for Trustees.....	42 850	15	11
Acts of Parliament.....	72 568	5	11
Construction of works, harbour.....	1 223 245	4	3
" " river	438 408	13	8
Elderslie rock	70 414	0	5
Engineering and surveying	20 032	14	11
Ballast.....	1 203	0	2
Kingston Dock, exclusive of land.....	84 544	5	4
Dumbarton exemptions.....	5 097	5	2

	£.	s.	d.
Dalmuir workshops	28 718	4	6
Harbour workshops	1 817	9	3
Steam ferry-boats, etc.	37 878	17	9
Harbour passenger steamers, landing stages, etc.	33 771	2	0
Swinging buoys in Gareloch	1 154	14	10
Measured mile—Gareloch	34	19	1
Harbour tramways	42 212	14	3
Swing bridge at Kingston Dock	12 793	19	2
No. 1 graving dock, exclusive of land	134 867	9	11
No. 2 " " "	108 283	4	3
No. 3 " " constructing	20 765	0	0
Queen's Dock, exclusive of land	825 212	8	11
Workmen's houses at Dalmuir	15 328	18	0
Gas-lighted buoys and lightship	5 289	1	8
Cessnock Dock, constructing	196 669	19	10
" Acts of Parliament	11 774	2	9
Quay wall, entrance, Cessnock Dock	13 880	5	1
	£13 641 301	5	0

APPENDIX II.

CLYDE NAVIGATION.

STATEMENT OF GROSS REVENUE FROM JULY, 1752, TO JUNE 30TH, 1892.

	£	s.	d.		£.	s.	d.
From July, 1752,				1787	1 975	16	4
to July, 1770	£147	0	10	1788	2 064	5	9
One year to July,				1789	2 153	15	6
1771	1 044	10	0	1790	2 239	0	4
1772	1 220	1	9	1791	3 175	14	1
1773	1 494	1	0	1792	2 739	5	7
1774	1 454	4	4	1793	2 840	17	11
1775	402	3	8	1794	2 936	14	11
1776	1 984	0	7	1795	2 836	5	9
1777	1 397	0	7	1796	3 649	14	4
1778	1 733	19	5	1797	3 182	6	0
1779	1 540	1	8	1798	3 199	1	6
1780	1 515	8	4	1799	3 233	18	3
1781	1 721	5	8	1800	3 319	16	1
1782	1 420	16	8	1801	3 400	10	9
1783	1 450	16	8	1802	4 085	15	11
1784	1 120	0	0	1803	4 640	16	10
1785	3 256	18	10	1804	4 193	7	7
1786	1 980	14	10	1805	4 065	10	5

	£.	s.	d.		£.	s.	d.
1806.	4 299	14	3	1850.....	64 243	14	11
1807.....	5 000	5	9	1851.....	68 875	4	9
1808	5 472	0	9	1852.....	76 077	9	4
1809.....	5 407	9	8	1853.....	77 919	18	6
1810.....	6 676	7	6	1854.....	86 580	5	11
1811.....	4 755	3	8	1855.....	73 943	9	1
1812.....	4 597	19	7	1856.....	74 995	7	9
1813.....	5 169	13	9	1857.....	82 797	10	7
1814.....	5 275	6	11	1858.....	78 783	17	6
1815	5 902	2	8	1859.....	90 816	17	7
1816.....	5 843	7	8	1860.....	97 983	18	1
1817.....	7 028	0	7	1861.....	105 768	11	0
1818.....	7 732	18	11	1862.....	111 493	10	2
1819.....	7 386	2	10	1863.....	118 083	7	10
1820.....	6 328	18	10	1864.....	121 380	13	9
1821.....	8 070	2	2	1865.....	121 587	11	11
1822.....	7 984	3	8	1866.....	125 787	10	0
1823	8 380	16	4	1867.....	131 892	2	6
1824	8 555	0	0	1868.....	143 840	17	3
1825.....	8 367	11	7	1869.....	150 136	4	5
1826.....	16 204	6	6	1870.....	164 093	2	10
1827.....	14 316	15	9	1871.....	164 188	18	7
1828.....	17 669	14	10	1872.....	174 200	12	2
1829.....	20 194	10	4	1873	182 906	15	2
1830.....	20 296	18	6	1874.....	192 127	16	11
1831.....	18 932	0	7	1875.....	196 326	18	10
1832.....	22 496	0	3	1876.....	198 526	19	6
1833.....	21 578	5	2	1877.....	208 732	1	0
1834.....	22 859	14	10	1878.....	217 100	0	3
1835.....	33 676	16	3	1879	211 501	11	8
1836.....	37 544	5	5	1880.....	223 709	0	8
1837.....	37 644	16	0	1881.....	248 061	14	0
1838.....	39 030	1	0	1882.....	264 549	8	3
1839.....	47 879	11	10	1883.....	283 998	8	5
1840.....	46 536	14	0	1884.....	291 182	4	11
1841.....	49 665	15	7	1885.....	291 658	4	11
1842.....	40 678	16	8	1886.....	282 912	1	3
1843	43 301	2	0	1887.....	287 933	17	9
1844.....	41 286	18	8	1888.....	311 495	1	6
1845	45 869	10	11	1889.....	331 492	18	9
1846.....	51 198	12	2	1890.....	356 202	11	3
1847.....	59 017	2	9	1891.....	354 580	11	8
1848.....	60 621	8	1	1892.....	369 226	6	5
1849.....	59 034	14	1		£8 890 279	7	5

VOL. XXIX. No. 606.
TRANSACTIONS OF ENGINEERS
DEAS ON RIVER CLYDE
AND GLASGOW HARBOUR
PLATE I

SCOTLAND
WEST COAST

RIVER CLYDE

FROM GREENOCK TO DUMBARTON

Surveyed by Staff Commander J R Elliot R.N

1880

The Coast line from Ravenscraig to Ardmore Bay and with the adjacent soundings are From the survey of Captain C G Robertson R.N 1846
The Channel above Port Glasgow re-sounded by the Engineers of the Clyde Navigation Trust, 1878
Greenwich Square 55° 56' 45"N 4° 45' 12"W

H.W.F.&C. at Greenock, 6h 0m Lagged. Springs rise 13 ft Neaps 10 ft Range 20 ft

I Fixed, Fl Fl. Flashing, Occ Occulting, Rev Revolving, Lights.

Figures on the land and those underlined on the banks, show the heights in feet above Low Water ordinary Spring Tides
Soundings reduced to the level of Low water ordinary Spring Tides. Between Port Glasgow and Dumbarton, the Soundings are reduced to an average Level of 5 Feet below Ordnance Datum.

The Depth and Soundings upon the Port Glasgow side of the Channel are referred thereto upon the South Pier side are referred to

Magnetic Variation in 1880 decreasing 7' annually

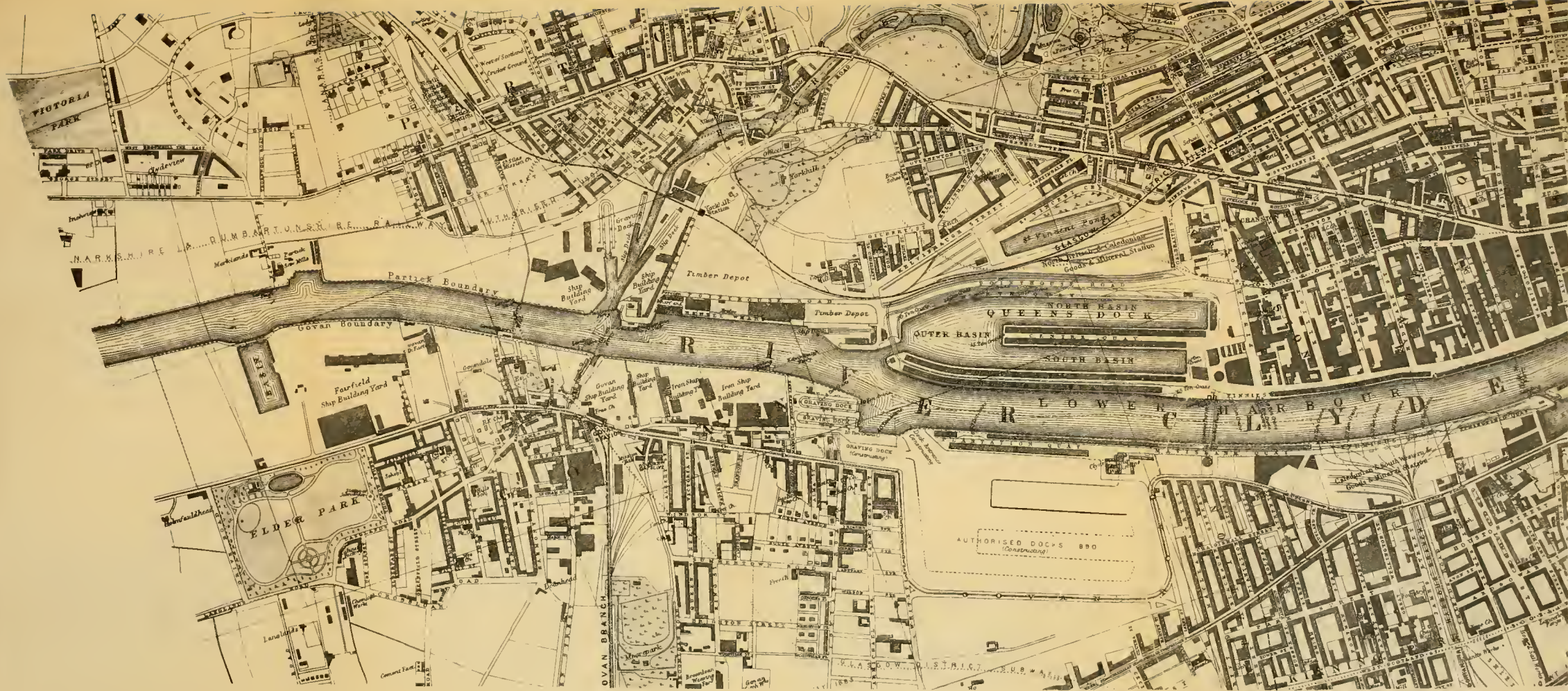
SOUNDINGS IN FEET

This is one of the Two Sheets of the Chart of the River Clyde, referred to in my Paper on the History of the Conversion of the River Clyde into a Navigable Waterway and the Progress of Glasgow Harbour.

Engineer

VOL. XXIX No. 606

TRANSAM SOC CIV ENGRS
DEAS ON RIVER CLYDE
AND GLASGOW HARBOUR
PLATE II


VICTORIA PARK
Clydeview
NARKSHIRE LA DUMBARTONSHIRE RAILWAY AUTHORISED
Markland
Partick Boundary
Govan Boundary
Ship Building Yard
Timber Depot
Yorkhill
Yorkhill Station
Fairfield Ship Building Yard
Govan Ship Building Yard
Iron Ship Building Yard
GRAVING DOCK
NORTH BASIN
QUEENS DOCK
OUTER BASIN
SOUTH BASIN
LOWER HARBOUR
RIVER CLYDE
ELDER PARK
AUTHORISED DOCKS 880 (Constructing)
GOVAN BRANCH
GLASGOW DISTRICT SUBWAY
Lanelands
Cement Fact
Broomlean Weaving Factory
Govan Park
Moorpark
Freeth
Govan Station
Caledonian & South Western & Goods & Mineral Station
North British & Caledonian Goods & Mineral Station
St Vincent Pond
GLASGOW

VOL. XXIX No. 606.
TRANS AM SOC CIV ENGRS
DEAS ON RIVER CLYDE
AND GLASGOW HARBOUR
PLATE III

APPENDIX III.

CLYDE NAVIGATION.

DETAILED ABSTRACT OF EXPENDITURE FOR THE YEAR ENDED JUNE 30TH, 1892.

	£	s.	d.
General management and office expenses	12 037	0	2
Harbour expenses	22 032	18	9
General expenses	8 508	14	1
Law and Parliamentary expenses	1 178	13	8
Sheds	595	3	8
Taxes	19 500	12	8
Lighthouses on river	196	1	7
Dikes and beacons	1 433	13	7
Graving docks	2 470	14	9
Cranes	5 405	2	5
" coaling and mineral	7 832	3	4
Ferries, Harbour	10 451	17	10
" Govan	5 703	19	11
Harbour passenger steamers	10 946	15	4
Planks and rhones	1 761	11	3
Water	1 919	15	2
Weighing machines	354	13	0
Properties	490	9	1
Dredging account, proportion for maintenance	26 632	2	11
Ground annuals and feu duties	13 070	9	9
Interest and annuities	176 449	9	8
	£328 972	2	7

	£	s.	d.
Surplus revenue	40 254	3	10

APPENDIX IV.

CLYDE NAVIGATION.

DETAILED ABSTRACT OF REVENUE FOR THE YEAR ENDED JUNE 30TH, 1892.

	£	s.	d.
Tonnage dues on vessels	79 473	2	0
Dues on goods	201 022	11	9
Rents for timber yards and offices	2 924	1	9
Quay rents	215	8	0

	£.	s.	d.
Harbour tramways	1 539	15	2
Lower stages of river	1 952	12	2
Miscellaneous	1 838	4	6
Graving docks	11 458	6	2
Crane dues	9 265	5	2
Coaling and mineral cranes	10 663	4	4
Ferries, Harbour	13 132	12	0
" Govan	6 087	1	10
Harbour passenger steamers	12 373	11	9
Planks and rhones	1 096	13	1
Water	5 495	10	1
Weighing	1 614	16	4
Rents	7 536	13	9
Funded debt premiums	1 536	16	7
	£369 226	6	5

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

607.

(Vol. XXIX—July, 1893.)

DESCRIPTION OF THE LOWER WESER AND ITS IMPROVEMENT.

By L. FRANZIUS, Ober-Bau-Director, at Bremen, Germany.

Translated from the German by T. H. McCANN, M. Am. Soc. C. E., assisted by ALBERT BEYER, Chairman of the Architectural Branch of the German Technical Society of New York.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

I. GENERAL HYDROGRAPHICAL DESCRIPTION OF THE RIVER WESER, IN PARTICULAR PRIOR TO THE COMMENCEMENT OF THE IMPROVEMENT.

The River Werra flowing from the Thüringer forests, and the River Fulda flowing from the Vogelsgebirge and the Rhön, unite at Münden, forming there the River Weser. From Münden to Bremen, a distance of 366 km., the river is called the Upper Weser, and for a distance of 69 km., extending from Bremen to Bremerhaven, the Lower Weser. The

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

effluent of the river to the open sea proper, for a distance of about 59 km., is called the Outer Weser. The first stretch has about 41 600 sq. km., and the last two have, besides, about 6 600 sq. km. of drainage area. About 27 500 sq. km. of the first area embraces mountainous and steep hilly land, so that during freshets the rise in the river is very rapid and considerable. The average descent of the upper 45 km. is as follows: from Münden to Karlshafen, 1 : 2 100; at rapids, however, it is 1 : 300. In the second stretch of 160 km., from Karlshafen to Minden, interrupted by slack water, caused by a dam at Hameln, it is 1 : 3 000; in the last 161 km., from Minden to Bremen, it decreases from 1 : 4 000 to 1 : 6 500.

The mean annual water-mark at Münden lies 114.6 m., and that at Minden, 35.3 m., above the corresponding water datum at Bremen, which was established from observations taken during the years 1870 to 1879, and was found to read on the principal gauge at Bremen 0.714 m., as shown in Table No. 2. The volume, the corresponding water levels and the velocities of the upper river are given in Table No. 3.

TABLE No. 2.

Comparisons of Upper-Water Readings on the Gauge at the Grand Bridge at Bremen.

Years.	Mean Annual Water-Mark. Meters.	Years.	Mean Annual Water-Mark. Meters.
1870	+0.96	1882	+0.69
1871	+1.30	1883	+0.38
1872	+0.58	1884	+0.56
1873	+0.36	1885	+0.25
1874	—0.13	1886	+0.06
1875	+0 42	1887	—0.17
1876	+0.82	1888	+0.43
1877	+0.86	1889	+0.16
1878	+0.86	1890	+0.09
1879	+1.11	1891	+0.24
1880	+0.96	1892	—0.52
1881	+0.77		
Sum	7.14	Sum	3.90
Mean	0.714	Mean	0.30

Comparing, first, the water surfaces, there can be estimated for the Upper Weser between Münden and Bremen, within shore lines, about 3 300 hectares (8 154.63 acres), that of the Lower Weser from Bremen to Bremerhaven at about 6 600 hectares (16 309.26 acres), and that of

TABLE No. 1.

Calculation of Water Volumes and Velocities prior to the Improvement during one Tide, at Normal Flood and Mean Upper Water = 0.73 Bremen Gauge.

Designation of the profile by places.	Water volume W. cu.m. cross-section F. sq. m. velocity v. m. E. = Ebb. Fl. = Flood.	I. Flood at Bremerhaven—hours before high water at Bremerhaven.						II. Ebb at Bremerhaven—hours after high water at Bremerhaven.							Total amount of the water volume in cubic meters during—		Duration of the—		Mean-water volume per second. Cross-section and velocity per second.		Mean-water volume per second. Cross-section and velocity per second, during a whole tide.
		5^{57}	5	4	3	2	1	1	2	3	4	5	6	6^{28}	Flood.	Ebb.	Flood.	Ebb.	Flood.	Ebb.	
																	Seconds.	Seconds.			
1. Habenhausen	W	320	320	296	296	296	296	296	296	296	296	296	296	296						296	296
	F. E.	296	296	320	320	320	320	320	320	320	320	320	320	320		13 231 200		44 700		320	320
	v.	0 92	0,92	0.92	0,92	0,92	0.92	0.92	0 92	0,92	0.92	0.92	0,92	0.92						0.92	0.92
2. Bremen (Grand Bridge)	W	296	296	296	296	296	296	296	296	296	296	296	296	296						296	296
	F. E.	386	386	386	386	386	386	386	386	386	386	386	386	386		13 231 200		44 700		386	386
	v.	0.76	0.76	0 76	0.76	0,76	0.76	0,76	0.76	0.76	0.76	0.76	0.76	0.76						0.76	0.76
3. Bremen (Safety Harbor)	W.	296	297	297	296	296	296	296	296	294	294	296	297	298						296	296
	F. E.	406	406	406	406	406	406	406	406	406	406	406	406	406		13 231 100		44 700		406	406
	v.	0.73	0.73	0.73	0.73	0 73	0.73	0.73	0 73	0.73	0.73	0.73	0,73	0.73						0,73	0.73
4. Hasenbüren	W.	304	308	305	300	296	300	289	274	275	294	307	305	307						297	297
	F. E.	420	416	412	408	404	400	412	424	436	432	428	424	420		13 269 800		44 700		418	418
	v.	0,73	0.74	0.74	0 74	0.74	0.75	0.70	0.65	0.63	0,68	0.70	0.72	0.73						0.71	0.71
5. Vegesack	W.	326	333	325	312	304	272	176	199	293	329	342	334	333						297	297
	F. E.	565	542	519	496	473	460	527	604	660	657	634	611	588		13 262 800		44 700		560	560
	v	0.58	0.62	0.62	0.63	0.64	0.60	0.33	0.3	0,43	0 50	0.54	0.54	0.57						0,52	0.52
6. Fargo	W. E.	492	500	411	201	134_{40}				570	652	625	591	586		15 866 700		32 700		485	400
	W. Fl.					$_{20}52$	124	282	58						1 7 2 800		12 000		144		
	F. E.	1 018	912	806	700					1 664	1 548	1 526	1 220	1 124						1 230	1 230
	F. Fl.					965	1 230	1 495	1 760										1 220		
	v. E.	0.48	0.55	0.55	0 29	0.14				0.35	0.42	0.47	0.49	0.52						0.40	0.33
	v. Fl.					0 05	0,10	0.19	0.03										0.12		
7. Brake	W. E.	1 402	1 065	54_{15}					828	2 614	2 571	2 126	1 790	1 703		47 272 900		27 600		1 713	1 800
	W. Fl.		(f. 45 M)	1 495	1 764	2 255	2 307	1 735							33 056 100		17 100		1 933		
	F. E.	2 524	2 100						5 068	4 644	4 220	3 796	3 372	2 948						3 230	3 900
	F. Fl.			3 054	4 008	4 962	5 714	5 492											4 830		
	v. E.	0 56	0,51	0.01					0.16	0.57	0.61	0,56	0.55	0.57						0.53	0.46
	v. Fl.			0.49	0.94	0.45	0.40	0.30											0.40		
8. Bremerhaven	W. E	191_{37}						306_{40}	6 529	10 324	9 243	7 569	5 653	3 830		149 133 600		24 300		6 137	6 400
	W. Fl.	$_{20}1$ 275	2 569	10 223	8 656	8 013	6 256	$5\,094_{20}$							126 223 800		20 000		6 678		
	F. E.								10 970	10 056	9 112	8 228	7 314	6 460						7 890	9 700
	F. Fl.	6 460	7 728	8 996	10 264	11 532	12 800	11 884											11 500		
	v. E.	0.03						0 03	0.60	1 02	1,01	0.92	0 77	0.60						0.78	0.66
	v. Fl.	0 19	0.33	1.13	0.84	0.70	0,50	0.43											0.58		
9. Rothesand Lighthouse	W. E.															1 108 000 000		22 620		48 983	49 300
	W. Fl.														1 095 000 009		22 080		49 592		
	F. E.																			130 400	136 300
	F. Fl																		140 900		
	v. E.																			0.38	0.36
	v. Fl.																		0.35		

Remarks.—These certain hours during which, for a time, ebb as well as flood existed, are marked by the small numbers which indicate minutes (') and follow or precede the numbers giving the water volumes.

TABLE No. 3.

Comparisons of the Velocities and Volumes of the Upper Weser at Tide Limits.

Water-mark on the gauge on the Grand Bridge at Bremen.	Velocities in meters per second.						Cross-section. = F			Water volume. = W			Remarks.
	The Big Weser.		The Little Weser.		The whole stream.		The Big Weser.	The Little Weser.	The whole stream.	The Big Weser.	The Little Weser.	The whole stream.	
	On the surface. v.	Mean. vm.	On the surface. v.	Mean. vm.	On the surface. v.	Mean. vm.							
m.	m.	m.	m.	m.	m.	m.	sq. m.	sq. m.	sq. m.	cu. m.	cu. m.	cu. m.	
0	0.67	0.52	0	0	0 67	0.52	293	.....	293	150	0	150	0.73 was the mean annual water-mark from 1870 to 1879.
0.73	0.96	0.76	0	0	0.96	0.76	387	.....	387	296	0	296	
1	1.04	0.81	0	0	1.04	0.81	418	.....	418	340	0	340	For the readings 1 to 5 the respective factors were obtained from the curves of the graphical plotting.
2	1.35	1.07	0	0	1.35	1 07	543	.....	543	580	0	580	
3	1.65	1.30	0	0	1 65	1.30	668	.....	668	900	0	900	
4	1.43	1.18	1 32	1.06	1.40	1.13	810	510	1 320	930	540	1 470	
5	1 90	1.56	2.13	1 76	2.09	1.17	940	583	1 523	1 465	1 035	2 500	
5 22	2.02	1.69	2 15	1.79	2.10	1.72	966	600	1 566	1 620	1 070	2 690	Highest water-mark, December 27, 1880.
5.54	2.28	2.41	2.00	1.90	2.24	1.94	1 004	620	1 624	1 910	1 240	3 150	Highest water-mark, March 13th, 1881.

To the maximum of 3 150 cu. m., measured directly in the Weser itself, must be added an approximate amount of 1 000 cu. m. for a lateral overflow on the left bank above Bremen, and which only found its way back into the Weser through the Ochtum Valley.

the lowest, a tide funnel extending from Bremerhaven to the mouth proper, at 53 000 hectares (130 968.30 acres). The water surface of the tidal section therefore exceeds considerably that of the upper river, the area of which, including its tributaries, may be estimated at from 6 000 to 7 000 hectares (14 826 to 17 297 acres). The volume of water moving in the tidal section exceeds to a far greater extent that which occurs in the upper river. For a mean volume of 150 cu. m. per second of summer flow at Bremen, there are at Bremerhaven, 6 400 cu. m. per second which form the mean volume of a whole tide, and at the mouth, 56 000 cu. m.

The greatest flow of the upper river water, which amounts at Bremen to about 4 000 cu. m., is opposed, however, at Bremerhaven, when the flood tide is 1.5 m. above the ordinary high water-mark, by a mean volume of 12 000 cu. m., and at the mouth by at least 100 000 cu. m. If, instead of the mean movement in the tidal section, we consider the maximum movement at half ebb and flood tide, then these figures will be nearly doubled. In accordance with these conditions, the influence of the upper water ceases to be felt at Brake.

As already stated, the arithmetical mean of the daily readings of the river gauge at Bremen was obtained from observations taken during the 10 years between 1870 and 1879, and was established as 0.714 m. on the principal gauge at Bremen. A higher level than 0.714 m. occurred on an average during these 10 years on 147.6 days, and a lower level on 217.6 days per year.

The water level stood at nearly uniform elevation in Bremen for a considerable length of time, since during 82.4 days it ranged from —0.5 to 0, and for 77.5 days from 0 to 0.5 annually. The so-called normal or ordinary level, which the water in any year was as often above as below, was 0.5 m. The duration of high upper river water rapidly decreases with its height, so that a reading of 4 m. occurred only during 1.9 days in a year. It is again emphasized that since the improvements of the Lower Weser have been commenced, all the water levels at Bremen show a lowering, as compared with earlier observations. As the improvements have not yet been completed, the old conditions are used as the basis for the purposes of this paper.

Aside from these changes, it is only in the upper part of the tidal section that the influence of the upper water is appreciably perceptible, and it is also observed that near the tide limits at Bremen the effect

of the upper water depends mostly on the mean annual water level, while the separate tidal phenomena in the upper part of the tidal section can best be recognized at lowest water. Thus, while before the improvement the water level stood at 0 at Bremen, during the half year comprising the summer months the mean high-tide reading was 0.15 m.; whereas, during 1892, after the summer water level had in the mean time lowered to —1.06 m., the mean high-tide reading was 0.69 m. Formerly the ordinary tide limit was a little above Bremen; since the improvement, however, it has moved up stream about 7 km., and will probably advance still farther up.

Table No. 2 shows that the mean-water level at and above Bremen, from 1880 to 1891, was, on an average, lower than during the period from 1870 to 1879. The mean annual water level was particularly low in the years 1886, 1887 and 1890.

A solid ice crust, which does not occur at Bremen every year because of the nearness of the sea, and which rarely extends farther down stream than Brake, hinders the tide movement in the upper tidal section; on the other hand, high tides will break up any ice crust below Vegesack and cause it to be carried down stream.

Of all the matter brought down from above to the beginning of the tidal section, the finer material settles only in the lower portions thereof, in branches and protected bays, along with the silt which is washed up stream from the sea, while the coarser sand and gravel settle sooner in many places, principally in the stretch between Farge and Brake. Large gravel is deposited only in deep channels where the strongest currents prevail.

For a full understanding of the action of the tide wave in the Lower Weser, it must be observed from the sea. If the directions of the Jade, Weser and Elbe, at their lowest parts, where they discharge into the sea, were produced, they would meet at a very sharp angle at Helgoland (see Plate I). It is possible to follow their beds and still more so their currents to within 30 to 40 km. of Helgoland. The tide waves of the North Sea approach Helgoland, and hence also the confluence of these external river currents, from a northwesterly direction; therefore the same tide wave throws one part into the Weser and the immediate adjoining part into the Jade and into the Elbe, so that in relation to the tide these rivers can be considered as branches of one trunk.

It is highly interesting to note that, based upon a number of tide curves for the year 1889, at Helgoland a mean tide difference of only 1.84 m. was found to occur; whereas, according to the Hydrographic Bureau, such difference is 3.1 m. at Cuxhaven, 3.3 m. at Bremerhaven, and even 3.8 m. at Wilhelmshaven. It must be observed that on account of the comparatively short period during which careful measurements have been taken, particularly with self-registering gauges, all these statements are not to be regarded as exact. These great differences can be explained by allowing for the position of the observation points, and the variation in the shape of the river mouths. Cuxhaven being the most seaward, lying on the extreme border of the tide funnel, and having the longest river behind it, of course receives the least obstructed tide wave. More favorable conditions for heavy piling up of the tide exist at Bremerhaven and even more so at Wilhelmshaven.

While Helgoland (see Plate I) is virtually free on all sides, a marked funnel formation is noticeable at the first point of observation, lying 39 km. landwards, which is the lighthouse on the "Rothensand," near the mouth of the Weser; the action, however, affects only sand bars lying deep under low-water level, and for this reason the tide gains 0.84 m. in range from Helgoland to that point, that is, changing from 1.84 to 2.68 m.

From Rothensand lighthouse, for a farther distance of 45 km. landwards to Bremerhaven, where, as previously stated, a tide difference of 3.3 m. is found, another increase of 0.62 m. in tide elevation takes place. The difference in harbor time of the last two places is one hour and twenty-eight minutes, from which is deduced a velocity for the high-tide crest of 8.52 m. per second.

At Bremerhaven the tide elevation reaches its maximum, while it gradually decreases up stream because of still existing irregularities of the river-bed, and disappears entirely about 7 km. above Bremen. It is evident that with the advancing improvements all tide conditions above Bremerhaven must change, and upon this depends the success and the permanence of the improvement works. The low-water surface, especially of the upper stretch, will be considerably lower; for instance, at Vegesack it will be lowered about 1 m., while high-water level will be changed very little. At the same time the progressive velocity of the tide wave will increase materially, so that the increased space contained between high and low water will be more quickly

filled by the up-running tide wave. This increase is clearly shown by the hourly water-level curves noted before and after the improvements were made (see Plate IV).

II. Principles Underlying the Improvements Projected by the Writer.

The object of the improvement of the Lower Weser is the making of a uniform and deep channel in the entire upper tide basin above Bremerhaven, and the maintenance of the created conditions by means of the increased and regulated current power, and with little other assistance. The means to accomplish this object is the formation of a regular river-bed, gradually narrowing up stream in accordance with positive laws, so as to impede as little as possible the free movement of the water.

To gain this it is necessary to do away with all sharp bends and irregularities of the channel, and especially all breaking or splitting of the stream, as these always oppose the movement of the water. In order to fix the bed, no projecting works, such as groins or dikes, should be constructed, as they unavoidably set back the water up stream.

Although the back-water or rise produced by a single groin is small, yet, by adding a larger number of these, it attains a considerable magnitude. Such back-water is, however, equivalent to a corresponding decrease of flood-tide volume, and tends to weaken the effect of the tide wave in that particular neighborhood. The less impeded the tide wave is at every point, the larger will be the water volume flowing up stream with the flood tide, and in like manner the current power will be increased as well with the incoming tide as with the deeper outgoing ebb.

The increase of current power is proportional to $\frac{m\,v^2}{2}$, that is, it is proportional to one-half the product of the water mass into the square of the velocity; and this increase must be considered as the most important principle in the improvement of a river's tidal channel, for with it the ability of a river to move sediment, and hence its power to deepen and maintain its bed, also increases.

It was upon these principles that the project for the improvement of the Lower Weser was based. In the first place, it was necessary to

fix the conditions as they actually existed before the commencement of the improvement. To this end all bottom contours, which had been obtained from carefully made soundings, were plotted on existing maps to a scale of 1 : 4 000 and at 1 m. apart. Further, the water surface for every hour was plotted in profile, as it was obtained from the graphical records of the existing self-registering gauges, thus obtaining the so-called tide curves.

By means of the distance between these water-surface curves and the corresponding areas of the water surface, the volumes of water passing hourly a given point of observation were computed, and from the volumes and the corresponding cross-sections the mean velocities for the stated intervals of time were determined. The volumes, cross-sections and velocities at each gauge station were then graphically plotted, and from these plots mean values were obtained.

In this way the important actual conditions which existed prior to the commencement of the works were ascertained, and by their use the analogous values which might be expected to follow the improvements were determined in a speculative way. To do this, however, it was necessary, in the first place, to decide upon the mean high and low water lines which could be expected after the completion of the improvement. These were fixed by carefully considering all possible influences, as well as by preliminary computations and estimates, and then making them the basis of future calculations. The high water-line showed only an insignificant rise at the upper end of the stretch proposed to be improved, while the low water-line showed a considerable lowering in spite of the fact that the most favorable assumptions were studiously avoided.

The approximate form of the future river-bed having thus been decided upon, the entire tide intervals of the different points, as obtained from the high and low water-lines, were divided into an equal number of parts. From the flood-tide curve for Bremerhaven, for which only an insignificant change was presumed to result from the improvements and from the progressive velocities (calculated by Green's formula $C = \sqrt{2\,g\,t}$) of different points of the ascending half of the tide wave, the time changes for the corresponding subdivisions of the tide curves of the different points as compared with Bremerhaven were ascertained, and, therefore, also the absolute times of the water levels corresponding to those subdivisions, so that the ascending half

of the tide wave could be plotted through these points. In order to ascertain also the descending half of the tide curves, there were selected out of a large number of actually measured tide curves those which showed in their ascending halves the greatest conformity with the newly plotted flood-tide curves, and from these the still unknown ebb-tide curves were then taken.

The next step taken was the fixing of the water-surface curves of the newly determined volumes and velocities. By means of diagrams, comparisons and the calculated surface slope of the future low water, both the assumed low water-line and the assumed form of the channel were modified until a satisfactory agreement of all results was finally obtained.

Particular value was placed on the proper development of the cross-sections. The latter, as shown on Plate III, Fig. 2, consist of two parts which differ materially, viz., the deep central part, which forms the low-water channel and serves as the navigable water-way, and the shallow side parts, the bottoms of which are about on a level with the low water-line. While the last-mentioned parts are capable of containing a large volume of water, the velocity therein will be insignificant on account of the shallow depth, so that only a small portion of the current power will there be used up. Nearly the whole of the current power is therefore available for the low-water section, to which the water movement is almost exclusively confined; whereas, the side portions during flood tide are filled from the middle section, and empty themselves back into it during ebb tide, thus operating like elongated flushing basins (spülbassins).

The low-water channel is therefore protected as much as possible against the deposition of sediment, while the water which flows from the central channel over into the adjacent side channels during flood tide suffers a loss of velocity and causes deposits therein. In order to produce the described cross-section, low guiding dikes were made of sunken fascines, so placed as to cover in some localities both sides of the low-water channel and only the concave side in others, in order to provide a safe and unchangeable boundary. These guide works reach only to low water, and are, therefore, very little exposed to the action of currents or ice.

The filling in of the spaces back of the dikes is made partially by direct filling with dredged material; while for future deposits from the

river itself, there is still remaining along the improved channel sufficient space to contain 19 000 000 cu. m. of material.

Between the guide dikes there is just sufficient cross-sectional area to permit the water volumes, which are present shortly before and after low tide, to move without special difficulty, so that no "serpentining" of the water shall occur. For this reason there was no hesitation about laying out the axis of the river for long distances in a straight or nearly straight line, since in the author's opinion there is no necessity for the curving of a river if the bed is properly formed for the smallest amount of flow.

As shown in Plate II and Plate III, the low-water channel which is enclosed by the guide dikes gradually widens in going down stream, but not uniformly ; furthermore, the width of the high-water channel also increases continually in going down stream, excepting at Brake and Nordenham, where two contractions exist, which could only be avoided by incurring unreasonable expense. As the side portions of the improved channel have only a limited share in the conveyance of the water, these contractions are very unimportant. At the designated points, these contractions even operate to advantage, in consequence of the admissible enlargement of the low-water section in the harbor fronts of Brake and Nordenham. The high-water channel is not arranged symmetrically with respect to the low-water section, because a symmetrical arrangement would have required a double amount of excavation on account of the irregular shape of the old river-bed.

It was necessary, without regard to cost, to do away with the most prominent faults of the old river-bed, such as the large splits between Vegesack, Elsfleth and Brake, and also those at Strohausen and Dedesdorf. At the Strohausen Plate the improvement was made by shutting off the branch which was at the time much the larger, but also the most curved, in favor of the shallower but straighter branch.

In estimating the cost, it was of the utmost importance to know how much material would have to be removed either by dredging or by current action. Although the execution of the improvement was so designed as to provide for cutting off the side channels first, both in order to secure the greatest aid from the current to the main channel as well as to deposit in the most favorable manner the material dredged from the main channel, still it was to be presumed that much more dredging would here be necessary than in the improve-

ment of upper river channels, because in a tidal channel a stronger current can be created only by first removing the shoals and bars. While it may not appear impossible to accomplish the improvement of a tidal channel by means of correctional structures such as dams and dikes alone, yet the result would in most cases be effected much too slowly and would often be rendered doubtful on account of accidental conditions such as spring tides, storm floods, ice, etc. On the other hand, it is often feasible to leave to the current the removal of a not insignificant amount of material, especially of the lighter kind ; and for that reason, of the total of 55 000 000 cu. m. of material to be removed from the Lower Weser, it was assumed that 31 000 000 cu. m. would have to be removed by dredging and digging, and 24 000 000 cu. m. by the ebb and flood currents.

It is self-evident that both in the section under improvement as well as in that below it, sufficiently large areas must exist on which the scoured material can be deposited without damage. Furthermore, it is necessary to secure an increase of current below the portion under improvement by augmenting the volume of water moving in the latter ; otherwise there would be a deterioration of the channel, because the sediment carried along would be deposited there in greater quantity. In the Lower Weser it was calculated that the increase of water volume passing Bremerhaven amounts to fully one-sixth more than the original volume, so that below Bremerhaven an improvement of the river channel will also be attained, inasmuch as the suspended material will not appreciably increase the height of the extensive lateral shoals.

Although the Lower Weser between Bremen and Bremerhaven had previously been partially improved at the sole expense of the State of Bremen, it was not until 1891 that the States of Prussia, Oldenburg and Bremen adopted, as a joint undertaking, the project of the author for the improvement of the Outer Weser, that is, the portion of the Weser below Bremerhaven. This had for its object the removal of a bar which was the result of a split in the river which had existed for 30 years and caused the formation of a continually growing shoal about 7 km. in length.

This improvement consists essentially in the construction of a guide dike about 6 km. long, commencing at a projecting angle near Blexen, and which will be extended down stream in as straight a line as practicable. Whether and to what extent it may be connected by

TABLE No. 4.

Comparisons of the Water Volumes, Velocities (in the mean per Second during one tide) of Normal, High and Low Tide before and after the Improvements with Reference to the Different Heights of the High Water-Marks.

Designation of the profile by places.	Mean water volume per second, cu. m. Cross-section and velocity per second during the whole tide.	Averaged Tides.				Various actual Tides.				
		I. Before the improvement.		II. After the improvement.		5.	6.	7.	8.	9.
		1. Normal tide and mean upper water = 0.73 m. Bremen gauge.	2. Normal tide and low upper water = 0. m. on the Bremen gauge.	3. Normal tide and mean upper water = 0.73 m. Bremen gauge.	4. Normal tide on low upper water = 0. m. Bremen gauge.	High tide October 18th, 1879, and low upper water = 0. o. m. Bremen gauge.	Normal tide on February 21st, 1879, and high upper water = 3.0 m. Bremen gauge.	High tide on February 21st, 1879, and high upper water = 3.0 m. Bremen gauge.	Low tide March 17th, 1879, and high upper water = 0.3 m. Bremen gauge.	Normal tide and low upper water = 0. m. Bremen gauge.
1. Habenhausen	W.	296	150	296	150	135	900	900	900	150
	F.	320	230	406	310	210	630	630	630	230
	v.	0.92	0.65	0.73	0.49	0.64	1.43	1.43	1.43	0.65
2. Bremen (Grand Bridge)	W.	296	150	297	150	127	900	900	900	150
	F.	386	280	540	480	.....	.....	.....	....	280
	v.	0.76	0.54	0.55	0.40	.....	.....	.....	.....	0.54
3. Bremen (Safety Harbor)	W.	296	150	297	150	124	900	900	900	151
	F.	406	325	580	460	330	670	670	670	325
	v.	0.73	0.46	0.50	0.33	0 38	1.34	1.34	1.34	0.46
4. Hasenburen	W.	297	150	301	150	135	900	900	900	156
	F.	418	350	590	510	400	620	620	628	350
	v.	0.71	0.43	0.51	0 31	0.34	1 45	1.45	1 45	0.44
5. Vegesack	W.	297	161	346	330	204	900	898	900	164
	F.	560	505	630	570	600	760	780	700	505
	v.	0.52	0.32	0.56	0 53	0.34	1.19	1.15	1.28	0.32
6. Farge	W.	400	393	990	990	640	896	872	907	377
	F.	1 230	1 200	1 340	1 340	1 450	1 630	1 800	1 450	1 200
	v.	0.33	0.33	9 73	0.73	0.44	0.55	0.49	0 63	0.32
7. Brake	W.	1 800	1 807	2 670	2 700	2 456	1 462	1 894	1 298	1 865
	F.	3 900	3 900	3 390	3 390	4 700	4 000	4 160	3 .30	3 900
	v.	0.46	0 47	0.80	0.80	0.53	0.37	0.45	0 35	0.48
8. Bremerhaven	W.	6 400	6 416	7 510	7 600	9 217	6 323	7 236	5 173	6 542
	F.	9 700	9 700	8 690	86 90	11 400	9 400	9 850	9 100	9 700
	v.	0.66	0.66	0.86	0.87	0.81	0.67	0.74	0.56	0.67

cross-dikes with the left bank, which is a sand field lying between high and low water, is not yet determined, because some small vessels have a certain interest in maintaining an open channel there.

Soon after 5 km. of the dike had been constructed during the period from April to September, 1891, an average increase in depth of 0.3 m. was observed over about 1 sq. km. of the surface of the bar, and six months afterwards the increase in depth was 0.5 m. The increase in depth of the channel proper, in the fall of 1892, was 2½ m. To assist the action of the current upon this bar, dredging was done during the summer of 1892, which resulted very favorably, for while formerly in the neighborhood of the bar the navigable water was confined to a narrow channel only 100 m. wide, the width is at present 500 m.

III. Execution of the Improvement.

In order to secure the indispensable uniformity in the execution of the work, the chief technical management is vested in the writer, under whom is Bau-Inspector Bücking as first assistant, in addition to several engineers (baumeister), and about eight assistant engineers. The subordinates consist of several overseers, clerks, and a large number of dredge and boat captains and steam engineers. All dredging work is done by our own forces, while the improvement works are performed by contract. For the dredging, therefore, it was necessary to obtain a large number of dredges, transport vessels and other apparatus, of which a schedule is given in Table No. 5.

TABLE No. 5.

Schedule of Apparatus and Vessels Obtained for the Improvement of the Lower Weser.

Number.	Class.	Dimensions.				Greatest dredging depth. Meter.	Buckets.		Hourly capacity. Cubic meter.	Machines.	
		Length. Meter.	Width. Meter.	Depth. Meter.	Draft. Meter.		Contents Cubic meter.	Number.		Number.	Indicated Horse-Power.
A.—Bucket Dredgers for Working in the Open River Channel.											
1	A	35.2	7.0	2.9	1.25	7	0.25	34	120	1	70
3	A	34	6.85	2.8	1 25	7	0.20	33	120	1	70
1	A	37	6.85	2.8	1.25	9	0.18	37	120	1	70
1	B	32.8	9.0	3.3	1.50	8	0.30	35	180	1	170
2	C	42	8.8	3.2	2.00	9	0.44	35	250	1	200
1	F	47	7.1	2.5	0.86	4.6	.....	20	.....	1	20

TABLE No. 5—(*Continued*).

Number.	Class or Name.	Dimensions.				Rate of speed. Knots.	Capacity.
		Length. Meter.	Width. Meter.	Depth. Meter	Draft. Meter.		
	B.—Secondary Dredgers.						
	Apparatus for removing material dredged out of the river channel.						
	I. Pumping Dredgers.						
1	FG	43	6.80	4.0	3.0	10			70-100	1	300
1	FG	24.4	6.80	3.50	1.60	7			150	1	320
	II. Bucket Dredger, with Suction Dredger.										
2	F	33	6.10	2.58	1.2	7	0.317	32	150	2	90
2	G	24.4	6.80	3.50	1.6				150	1	320
1	G	25	8.5	2.4	1.5				80	1	150
	III. Scow Dredger (Bucket Chain Dredger).										
	This lifts the dredged material out of the scow and delivers it into railroad cars.										
	C.—Vessels for Transporting the Dredged Material.										
	I. Steam Scows.										
8	D	36	6.8	2.20	1.5	6	100
4	D	35	6.8	2.40	1.5	6	100
2	D	35	7.0	2.35	1.5	6	100
4	E	45	8.0	3.0	2.0	6	200
4	E	45	7.9	3.0	2.0	6	200
	II. Tugs and Common Scows.						
2	Nord u. Sud	20	5	2.075	1.5	8	
2	Ost u. West	17.2	3.6	2.1	1.4	8	
1	Pony	15.5	3.4	1.6	1.4	8	
12	Without bottom gates	21	4.6	1.6	1.15		35 cu. m.
48	With " "	22	4 8	1.8	1.20		40 "
	D.—Inspection Steamers and Launches.						
1	Tide	26	4.6	2.55	1.4	10	
1	Dünung	17.5	3.8	2.1	1.5	8	
2	Woge u. Bore	13	3.1	1.6	1.2	8	
2	Stau u. Welle	13	3.1	1.6	1	8	
2	Ebbe u. Fluth	11	2.2	1.2	1	8	
1	Vipp	9.5	2.4	1.4	1	$6\frac{1}{2}$	
1	Spring	9.3	2.2	1.21	1	$6\frac{1}{2}$	
	E.—Sailing Vessels.						
1	Kaus	Sailing yacht.					
	F.—Coal Hulks.						
10							

The greater part of all the apparatus was provided at the outset of the work, with the exception of the secondary dredges (pump dredges and flushing machines), as the latter were particularly necessary only after the filling up of the lateral branches of the river which were to be cut off, and which gradually became inaccessible to the dumping scows. Active dredging is stopped only in December and January, during which months all necessary repairs are thoroughly done ; during the remainder of the time the work progresses uninterruptedly day and night.

To accomplish this, the vessels and dredges are provided with double crews. All dredgers have electric lights, and on the water where the scows travel, small light-buoys are placed. These are cheaply constructed by fixing in two barrels a wooden frame on the top of which a lantern is carried in a light iron stand. The dredging work in the actual river channel is done with bucket dredges of the classes designated "A, B and C" (see Table No. 5). The dredged material is carried by 22 steam scows and 60 ordinary scows directly to the dumping places, if possible, and there emptied through the bottom valves of the scows ; but where, as above mentioned, these places become too shallow, the scows cannot be used during low water, because they are liable to run aground or to lose valuable time waiting for high water.

In order to remove the dredged material cheaply and without losing time in spite of this latter difficulty, there were introduced in the third year, 1890, two kinds of secondary dredgers (pumping or suction dredges and flushing machines). These are placed at convenient points along the bank, and relift the dredged stuff left there by the scows, and flush it away through flexible lines of pipe to a distance of several hundred (400 to 500) meters. The removal of the material, mixed with water in the proportion of 1 to 9, is accomplished in both kinds of dredgers by means of a large centrifugal pump worked with a horizontal shaft. The lifting of the material by the pump dredgers is accomplished by the same kind of centrifugal pump in connection with a suction pipe reaching to the bottom; whereas, in the other kind of secondary dredgers called flushing machines, this is accomplished by a chain bucket dredge attached temporarily to a scow carrying the centrifugal pump and into which the dredged material is emptied.

The chain bucket dredge can also work independently. Although this second kind of dredging apparatus is more expensive in first cost, and appears more complicated, yet it works cheaper than the first kind. The reason for this lies in the impossibility to work upon uneven ground with the suction pipe so uniformly as to avoid sucking up too much water. The work of the bucket dredger is much more uniform, because it requires only light buckets and chains on account of the thoroughly loose condition of the previously dumped material, and the efficiency of the centrifugal pump, which is by far the more powerful part of the combined apparatus, is materially increased. These flushing machines have also been used for actual dredging close along the shore, especially in lateral branches where the dredged stuff could be disposed of in the immediate neighborhood.

One of the greatest difficulties connected with the operation of the suction dredges was to keep united that portion of the piping which floats between the dredge whose position is continually changing, and that portion which lies fixed on the shore. While for the latter portion plain, straight, flanged sheet-iron pipes, 3 mm. thick, 0.50 m. in clear diameter, and 6 m. long, with some elbows were found sufficient, it was necessary in the other portion to make the tubing very flexible by special joints, and also to keep it floating on the continually changing water surface. The necessary flexibility was obtained after repeated experiments by the introduction of short connecting pieces between the separate pipes. These connecting pieces consist of a strong leather hose which is protected against exterior damage by an armor of steel wire netting with iron stiffening rings. The tubes are floated on pairs of sheet-iron cylinders of the length of the straight pipes, said cylinders being connected by wooden frames. At the ends of the wooden frames are iron bows to serve as bumpers, so that the pliable joints cannot be bent too much by wave motion, etc. At low water some of the tubes which float during high water rest upon the sloping shore.

The further the improvement progresses, the more important the operation of all these suction dredgers become, because of the fact that the water diminishes continually in depth over the area to be filled.

The acquisition of a seaworthy suction dredge for the improvement of the Outer Weser is not necessary for the present, for, notwithstanding the superiority of such apparatus, the work there which is

insignificant, can be done in favorable weather by the large bucket dredges.

Since the beginning of the improvement works the following quantities have been removed from the river channel during the respective years :

	Cubic Meters.		Cubic Meters.
1887	170 000	1890	4 100 000
1888	1 700 000	1891	4 270 000
1889	3 750 000	1892	3 480 000
Total			17 470 000

The cost for dredging and disposing together, including the secondary work done by the suction apparatus during the years 1890 and 1891, amounts per cubic meter to 0.48 mark (about 11.4 cents).* This includes :

(*a*) For a sinking fund, 10% on the first cost and maintenance, in round figures, 0.11 mark.

(*b*) The entire cost of administration, in round figures, 0.08 mark.

The actual cost of dredging and disposal of the material is therefore only about 0.29 mark per cubic meter. The cost per cubic meter of dredging and disposal by the suction dredges in the year 1891 was, exclusive of sinking fund, about 0.16 mark; including sinking fund, about 0.25 mark.

The construction of the improvement works, that is, the guide dikes as well as the closing dams, was vigorously pushed during the first few years in order to gain all possible co-operation of the current in the formation of the channel. All these works are made of brush which was worked up for the greater part into mats. In the construction of the guide dike in the Outer Weser, some of these mats had to be transported 10 km., because there was no suitable working place obtainable near the site of the dikes. The transportation of the mats, which are from 10 to 15 m. wide, 20 to 30 m. long by about 1 m. thick, and draw scant 0.5 m. depth of water, offered no difficulty in towing by small tugboats. These large bodies are somewhat elastic and therefore adjust themselves in some degree to the form of the river bottom ; they are placed over the designated localities between anchored vessels, and during quiescent water are loaded with stones from the vessels and guided exactly into place by means of ropes.

* 1 mark = 23.8 cents.

The lower strata of mats in the dikes are on an average 2 m. wider than the next following, so that the dike obtains a slope of 1 to 1 on both sides. The uppermost layers are usually only 4 to 5 m. wide. To equalize the irregularities of the surfaces of the mats, continuous layers of packwork with strong interlaced partitions or borders are made, and the spaces between the latter are filled in with quarry stones as closely as possible.

As already mentioned, the guide dike extends on an average only about 0.10 to 0.20 m. above low water, with the exception of the ends joining the higher shores, where they rise to about half-tide. This low position admits of the free motion of the tide water, and protects the dike against the injurious attack of the waves, and especially of the ice cakes. The particularly heavy ice movement of 1891 did no damage to any part of the works, which would hardly have been the case had they been constructed of stones only. On account of their noticeably advantageous influence, which was manifested during the progress of the improvement, more dike works were built than was originally contemplated.

Notwithstanding that about 450 000 cu. m. of fascines were used yearly from 1889 to 1891, and that a portion or the material for them had to be transported over 100 km., still there was no trouble to obtain it from the competing contractors. From the beginning of the improvement up to December 31st, 1892, the following materials were purchased for the making of mats: 2 100 000 cu. m. brush, 6 600 000 lin. m. of stakes of 6 cm. in mean diameter, 145 000 bundles of willow twigs (1 bundle = 100 pieces), 6 000 cu. m. of fence brush, 85 000 cu. m. of ballast stones, 370 000 kg. galvanized iron wire of 3.1 to 5 mm. thickness, and 132 000 kg. ropework. Out of these materials were made, in round numbers, 1 050 000 cu. m. of finished mats or packwork. From this it will be seen that there was used for 1 cu. m. of finished work 2 cu. m. of brush, 6.2 lin. m. of stakes, 0.14 bundle willow twigs, 0.0057 cu. m. of fence brush, 0.081 cu. m. ballast stone, 0.32 kg. of galvanized iron wire, and 0.12 kg. of ropework.

The cost of material delivered on the site was on an average as follows:

One and six-tenths marks per cubic meter brush, 3.5 marks per 100 linear meter stakes, 3.8 marks per 100 bundles willow twigs, 3.50 marks per cubic meter fence brush, 7.55 marks per cubic meter ballast stone,

24 marks per 100 kg. of galvanized iron wire, and 61 marks per 100 kg. of ropework. The cost, therefore, of material in 1 cu. m. of finished work was 4.2 marks, to which must be added 2 to 3 marks for labor; so that the cost of 1 cu. m. of finished work varies from 6 to 7 marks.

A few additional remarks concerning the improvement of the Lower Weser, and the peculiar attendant conditions, may also be admissible here.

The order in which the works followed each other made it necessary to harmonize the requirements of navigation with the theoretical principles of the improvement. In accordance with the latter, it would doubtless have been more advantageous to have commenced the works at the lower end and gradually progressed up stream. As, however, for reasons of policy, the free and Hanse town Bremen was obliged to build the free harbor below the city during the years 1885 to 1888, at a cost of about 30 000 000 marks, and could only commence the improvement of the Lower Weser in 1887, it was desirable to admit larger ocean vessels to the finished harbor as soon as possible; otherwise both the interest on the outlay for the harbor, and the advantages gained by the attractions of trade to the town, would have been sacrificed for some years. With these fundamental principles in view, the improvement works were so managed that from 1888 to 1892 the channel depth to Bremen was increased from 2.75 to 4.70 m. at ordinary high tide and mean river discharge; and as a consequence, 620 000 tons of arrivals and departures were already registered at the harbor of Bremen in 1891.

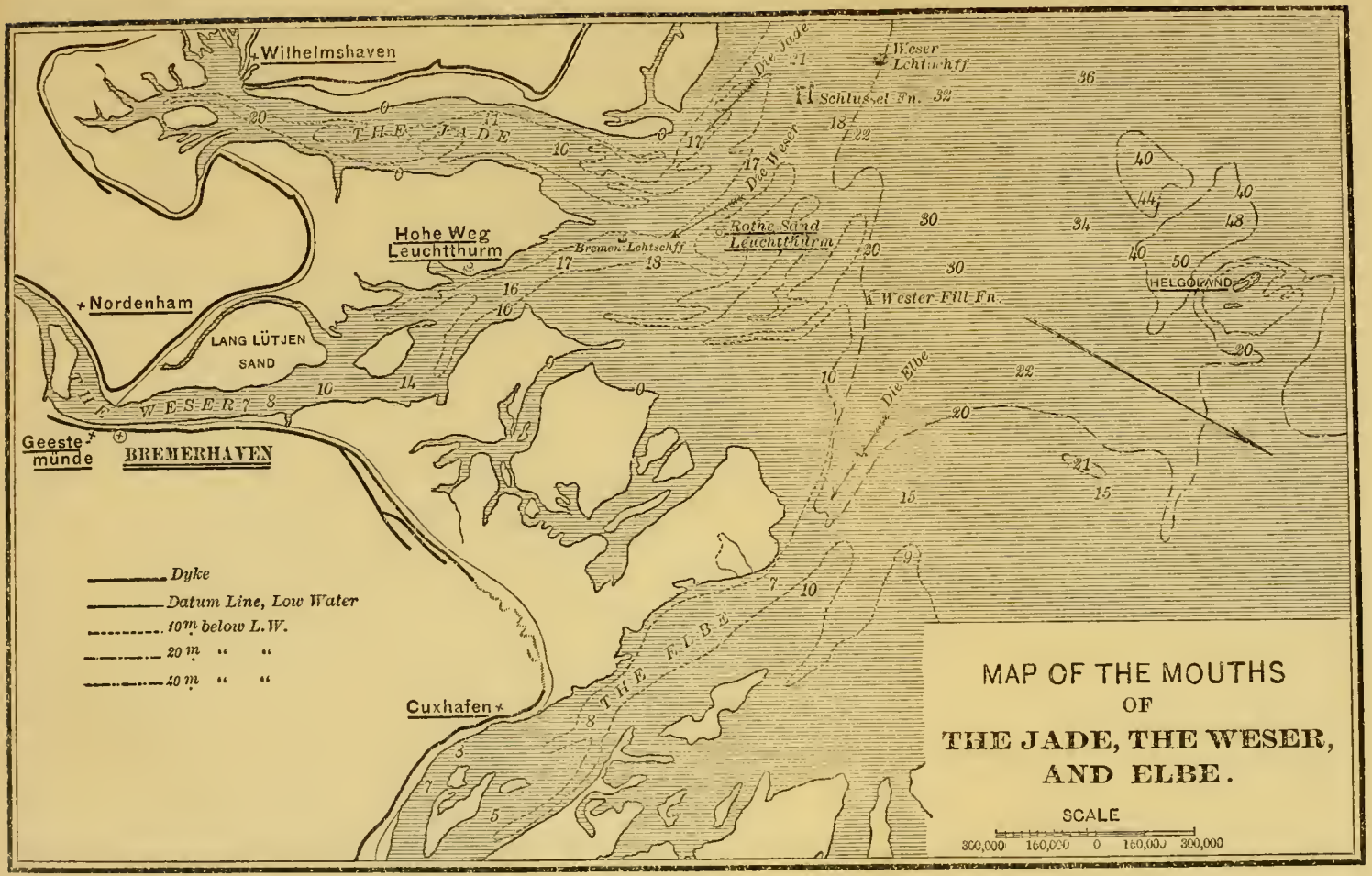
Another purely technical question is, whether the closing of the larger side branches should be done quickly or slowly. In accordance with the main object of the improvement, which was the attainment of the greatest possible water movement, it was essential not to block up a side branch appreciably more than the main branch could at the same time be enlarged, especially if the latter was small in the beginning. In that case, however, the progress of the entire work would be too slow. Where it is required to enlarge the main branch 1 000 sq. m. in cross-section, every kilometer of its length will furnish 1 000 000 cu. m. of material to be removed. If the split of the channel in question is several kilometers long, there results an equal number of 1 000 000 cu. m., the greater part of which would have to

be dredged to gain the required object. To do this would require several years, even with the use of a most elaborate dredging plant.

On the other hand, it is possible, in a few months to shut off a large side branch by the aid of the previously described methods, that is to say, by the construction of guide dikes above and below and a dam in the middle portion so that at the time of low water only a small quantity will flow through, while these dams being built low offer comparatively little impediment to the flow of the rising tide. By these means a powerful co-operation of the current power is obtained in the main branch, principally at the time of low water, whether it be ebb or flood. The result of this is that the main branch is rapidly deepened by the increased current action, and a portion of the scoured material which is conveyed beyond the upper and lower points of separation is carried into the side branch by the changing currents; and as the velocities are there diminished by the dikes, the greater part of the sedimentary matter is deposited.

There is opposed, however, to these advantages an unavoidable disadvantage from the fact that the low-water surface above the split in question is kept at a relatively high elevation until the main branch has become widened to such an extent that it alone, or in conjunction with the remainder of the side branch, can carry off as much water at the time of low water as both branches could before the improvements. This disadvantage is, however, temporary and must be endured for the sake of attaining the more important advantages.

Thus the low-water surface above the Strohausen Plate rose about 0.20 m. during the years 1889 to 1891 in consequence of the contractions made in the left branch. This rise, however, reached its greatest height in 1891, and will probably disappear about the beginning of 1893, because an appreciable deepening in the right-hand branch has occurred in the mean time, also because the dredgings there are being pushed with special vigor. Between 5 000 000 and 6 000 000 cu. m. of material were scoured into the left branch, and have been permanently deposited therein, which would not have been attained so rapidly or so cheaply had not such vigorous changes of the old conditions been made by means of the guide dikes and cross dams. Such a local raising of the low-water surface, moreover, does not necessarily cause a decreased water movement above. It is even possible to increase the same if the improvement works are carried on with suf-


Wilhelmshaven
THE JADE
Die Jade
Weser Lichtschff
Schlussel Fn.
Die Weser
Hohe Weg Leuchtthurm
Bremen Lichtschff
Rothe Sand Leuchtthurm
Nordenham
LANG LÜTJEN SAND
THE WESER
Wester-Fill Fn.
HELGOLAND
Die Elbe
Geeste münde
BREMERHAVEN
THE ELBE
Cuxhafen
Dyke
Datum Line, Low Water
10m below L.W.
20m " "
40m " "
MAP OF THE MOUTHS
OF
THE JADE, THE WESER,
AND ELBE.
SCALE
300,000 150,000 0 150,000 300,000

MAP OF THE WESER

FROM BREMEN TO HOHENWEG LIGHTHOUSE.

VOL. XXIX, No. 607.
TRANS. AM. SOC. CIV. ENGRS.
FRANZIUS ON IMPROVEMENT OF THE LOWER WESER.
PLATE III.

CROSS SECTIONS ON COMPLETION OF THE IMPROVEMENTS.

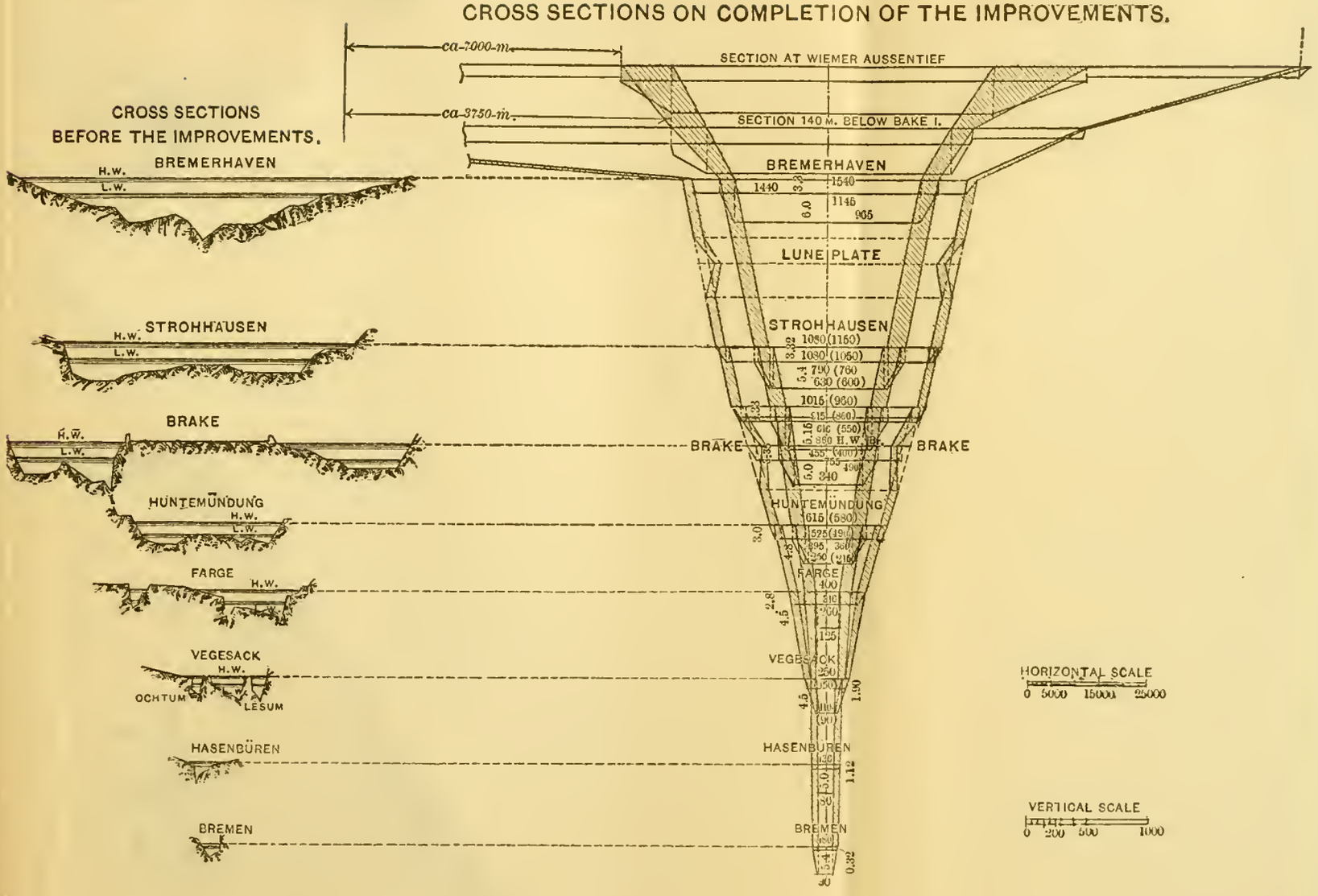
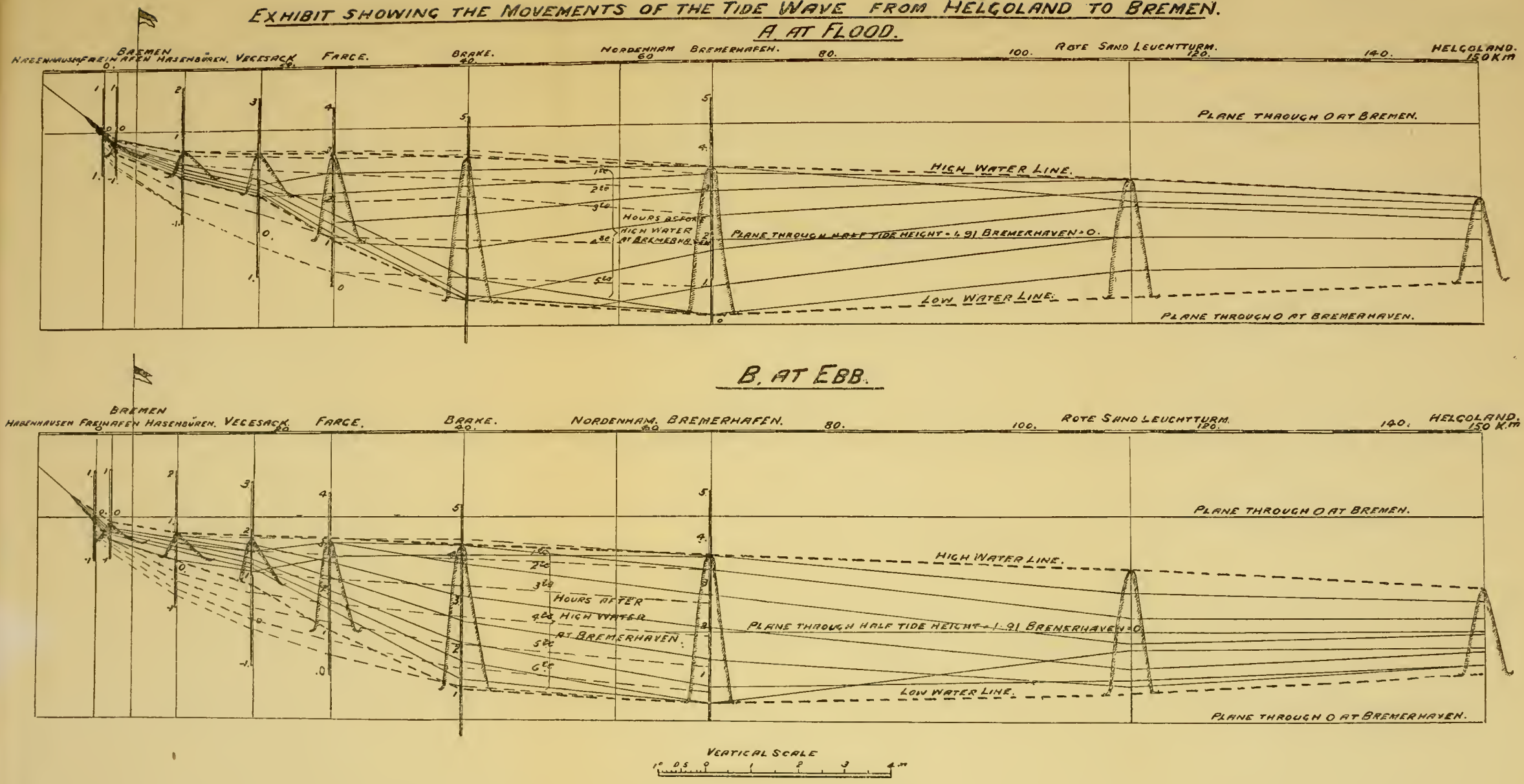
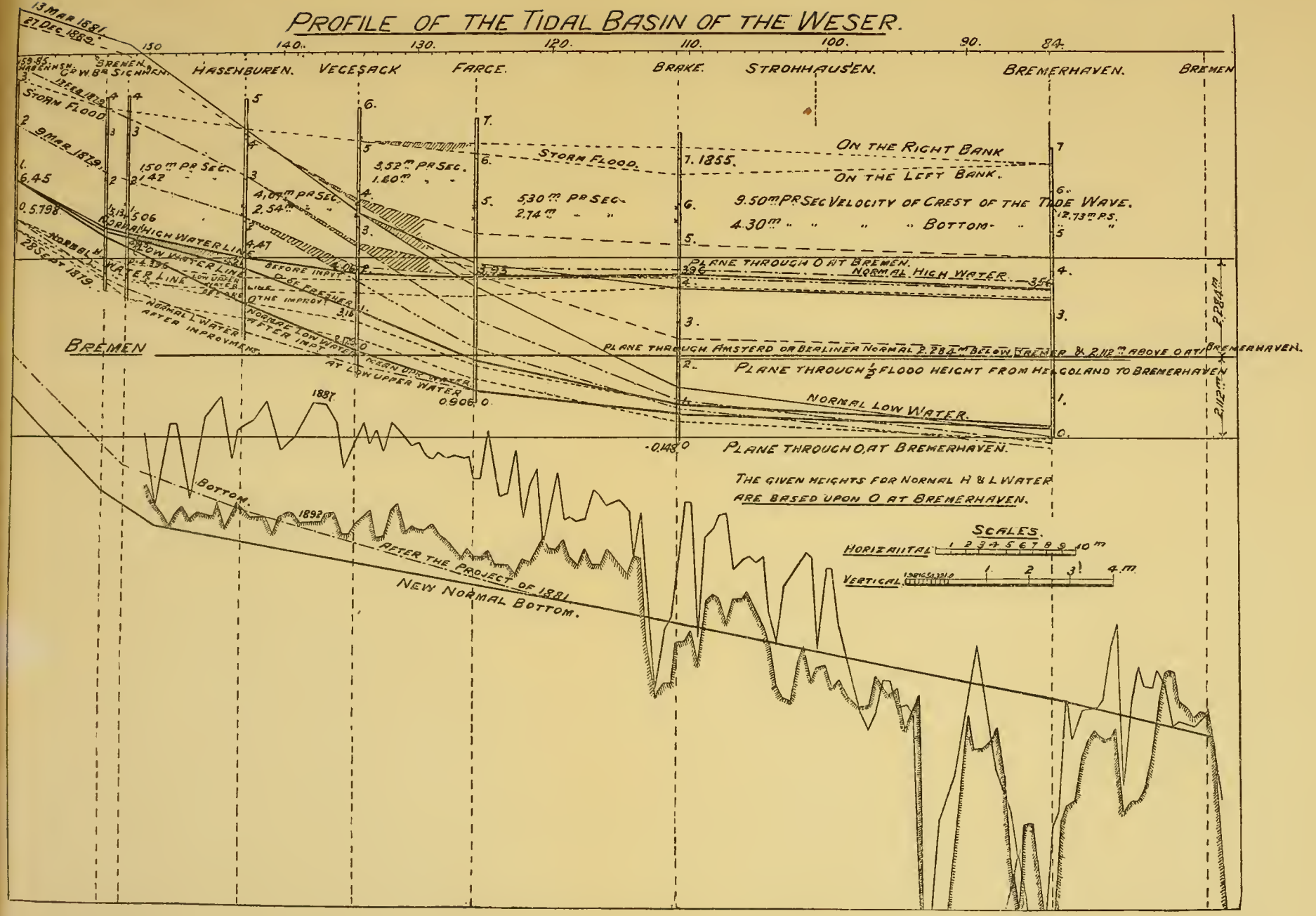


EXHIBIT SHOWING THE MOVEMENTS OF THE TIDE WAVE FROM HELGOLAND TO BREMEN.




PROFILE OF THE TIDAL BASIN OF THE WESER.
HASENBUREN.
VEGESACK
FARGE.
BRAKE.
STROHHAUSEN.
BREMERHAVEN.
BREMEN
ON THE RIGHT BANK
ON THE LEFT BANK.
9.50m PR SEC VELOCITY OF CREST OF THE TIDE WAVE.
4.30m " " " " BOTTOM
STORM FLOOD.
PLANE THROUGH O AT BREMEN.
NORMAL HIGH WATER.
PLANE THROUGH AMSTERD OR BERLINER NORMAL 2.284m BELOW BREMER & 2.112m ABOVE O AT BREMERHAVEN.
PLANE THROUGH ½ FLOOD HEIGHT FROM HELGOLAND TO BREMERHAVEN
NORMAL LOW WATER.
PLANE THROUGH O, AT BREMERHAVEN.
THE GIVEN HEIGHTS FOR NORMAL H & L WATER ARE BASED UPON O AT BREMERHAVEN.
BOTTOM.
AFTER THE PROJECT OF 1881
NEW NORMAL BOTTOM.
SCALES.
HORIZONTAL
VERTICAL

ficient energy. Thus, by the removal of the shoals at Elsfleth, above the split near Strohausen, previously mentioned, which was done intentionally in the first years of the improvement, a lowering of the ebb-tide surface was actually obtained which extended over the whole upper section of the improvement.

It is obvious that in all such far-reaching changes, the existing conditions must receive more attention than the purely technical requirements, and that the preliminary estimate must take into account all possible claims for damages. For this purpose it is essential to measure exactly all existing facilities for drainage; to take accurate soundings of all water channels; to determine the amount of salt in the water with reference to its use by cattle; to make investigations of the character of the local vegetation, with the view of its possible alteration by the improvement, etc.

The following is the preliminary estimate of the cost of the project:

	Marks.
For land purchase and damages	495 600
For excavation, dredging and transportation (31 000 000 cu. m.)	23 641 212
For correction works	2 748 860
For secondary works	950 000
For administration, incidentals, etc	2 164 382
Total	30 000 000

Some of these amounts have since been materially changed, especially the fourth item, which has been considerably exceeded, while in the second item a considerable saving was made in consequence of the exceedingly low price paid for moving material.

Up to the end of 1892 there has been expended:

	Marks.
For excavation, dredging, transportation	10 920 313.07
For correction works	5 236 111.71
For secondary works	2 688 117.99
For administration, incidentals, etc	1 620 475.48
Total	20 465 018.25

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

608.

(Vol. XXIX.—July, 1893.)

A BRIEF ACCOUNT OF THE BUILDING OF LEIXOES HARBOR.

By ALFONSO JOAQUIM NOGUEIRA SOARES, Inspecting Engr. in Charge.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Leixoes Harbor, situated about 5 km. to the north of the mouth of the River Douro, is formed by two break-waters, the northern one extending 1 579.37 m. in length, and the southern, 1 145.25 m. The outlines in plan from the shore are concave to seaward, as far as low-water level, in order to insure the best protection to the stoneyards and service roads, as well as to enlarge the area. Beyond this their advancement into the sea is in right and parallel lines, whose approximate distance is 1 100 m., and whose bearing is S. 73° 30′ W. They

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

then approach each other, curving towards the inside of the harbor, with 300 m. and 200 m. radius, respectively, for the north and south moles, and afterwards continue straight to their outer ends ; leaving an opening 220 m. wide for the entrance, but so that the break-water from the north extends about 150 m. further into the sea than the one from the south.

The north break-water, which in part rests upon several rocks that are visible at low water, and even at high tide, is the most important, as it completely shelters the harbor from the northwest swell of the sea, the most violent here.

The area of this harbor, measured at lowest water level (hydrographical zero), is about 95 hectares (234.75 acres). At high tide it is considerably larger, as it then includes the tide-basin of the River Lessa. The depths of 8 m. and more, indicated by the soundings figured in meters on the plan and represented by contour lines, also figured in meters as well as in English feet, are all referred to the hydrographical zero. The area within these contours covers an area of 40 hectares (98.84 acres), and the harbor admits the largest merchant ships, whose access is, in general, easy.

The construction of the break-waters in deep water was by what is called the mixed system. The lower structure or submarine basement is a mound of loose rubble stone, assorted in three different average sizes. The stones of the first or least size do not weigh more than 2 000 kg. each ; those of the second size range from this weight to 8 000 kg., and those of the third are still heavier. The seaward slope or foreshore is defended by artificial blocks, 20 cu. m. each in bulk and about 45 000 kg. in weight, made with rubble stone bedded in mortar and with concrete. The upper structure or sheltering wall is built with hewn stone faces and rubble stone backing, all of which is laid in mortar, these materials being joined in artificial blocks of about 20 cu. m. in the part most exposed to the sea.

The loose stone masses of assorted rubble, as well as the artificial blocks, are so placed that the most bulky materials occupy the positions most exposed to the destructive action of the waves. Accordingly, on the base for the upper structure, at the level of zero, the second-size rubble, that goes down 5 m. below this datum, is covered, in the first place, by third-size rubble, and after that, by the artificial blocks. These rise against the outward face of the upper

structure about 5 m. above datum, and descend below datum to the depth of 7 m., where they rest upon the third-size rubble mass, because at greater depth, the agitation of the sea not being so effective, great mass is not required for the defense of the inner less weighty materials. The breadth or thickness of the mound at datum is 38.24 m., the artificial blocks occupying the width of 15.8 m. between the seaward slope and the sheltering wall.

The upper structure is 5.4 m. thick at datum level, has its outward face battered 1 horizontal to 10 vertical, and has a height of 9.8 m. Its thickness at the top, barring the jut of the cordon, is 4.5 m., which is divided into 3 m. for the width of the walk and 1.5 m. for the base of the parapet, whose height, 1.4 m., makes the total elevation of the upper structure 11.2 m. above extreme low water, or 7.4 m. above the highest tide.

The upper structure, in addition to being protected on the sea side by artificial blocks to the height of 5 m. above datum, is on the harbor side supported by first-size rubble and by the pavement laid in mortar, which, at 6 m. above datum, forms the plane of the quay, 10 m. wide ; so that the thickness of the break-waters is 14.8 m. at the level of this plane. Below datum level the thickness or breadth of the mounds increases with the depth. The slope of the rubble on the harbor side is 1.33 m. horizontal to 1 m. vertical, and that of the artificial blocks on the sea side is 1 to 1 to the depth of 7 m., where the covering of this class terminates, being followed by that of third-size rubble, which still increases the breadth, as may be seen on the section.

The construction of the heads of the break-waters followed what is called the upright wall system. The foundations were formed with concrete in bags, so as to give regularity to the rock bottom, after the sand and movable detritus were taken away by means of dredges and the work of divers. The foundation of the north head is buried in the general bed of sand. The greatest thickness of the concrete in bags there is 2.7 m., and its upper surface, that on an average is at the same level as the upper surface of the sandbed, is 14.85 m. below datum. For the foundation of the south head advantage was taken of a large submarine rock which rises about 5 m. above the bottom, so that, to establish uniformity of surface in the same way by means of concrete in bags became much easier, a plane upper surface being left,

upon which the upright wall rests, at the depth of 9.9 m. below the datum level.

The height of the upright structures from their bases to this datum is, therefore, 14.85 m. and 9.9 m., respectively, at the north and south heads. In both of them the thickness of the rectangular part is 15.4 m., and the thickness or diameter of the circular part, 20 m. Below datum these structures were executed as follows: the circular part at the north head and the rectangular part at both of them were built with artificial blocks of various dimensions, but in general ranging in bulk from 16.5 to 20 cu. m., made of rubble stone bedded in mortar, which were placed in horizontal courses or layers, without mortar in the joints and beds. The circular part of the south head was built within an iron caisson that was lined with rubble stone bedded in mortar and filled in with concrete. After a coating of these materials had been laid dry-shod on the bottom and against the sides, the caisson was sunk in place, and was afterwards kept drained with a powerful centrifugal pump, in order to allow of the interior constructions being continued dry-shod, so as to form a compact body.

From datum to the quay level, 6 m. above, the heads were constructed with artificial blocks, hewn stone and stone rubble, all with mortar in the beds and joints, so that the masses are perfectly compact. Above the quay-plane, the upper structures or sheltering walls agree with those on the mounds and are constructed like them.

The principal materials of the country, stone for all sorts of masonry and sand for mortar, were of excellent quality and were found in very favorable working conditions. The cement came from the important establishment at Boulogne-sur-Mer with the mark "Demarle Lonquety & Cie.," in accordance with an agreement between the contractors of the works of the harbor and the manufacturers.

The mortar used in making the artificial blocks for the protection of the loose rubble masses and for the construction of the upright walls was made with this cement and sand, in the proportion of 556 kg. of the former to 1 cu. m. of the latter. That applied to the hewn stone outward coating of the sheltering wall above the quay-plane was also made with cement and sand, in the proportion of 600 kg. of cement to 1 cu. m. of sand, or of 1 of cement to 2 of sand, and that used in the backings was mixed with water-lime of the country (Cabo Mondego),

puzzolana, also Portuguese (Ilha de S. Miguel) and sand, in the proportions of 632 kg. of lime, 1 cu. m. of puzzolana, and 3 cu. m. of sand.

The entire work was taken at a lump sum (*a forfait*) by Dauderni and Duparchy, according to the plan and minute specification, in which every detail was determined. These contractors were, after Dauderni's decease, succeeded by Duparchy and Bartissol. The contract with the Government was closed on the 16th of February, 1884, in pursuance of public competition announced for January 23d of the same year, when the only proposal offered was that of these contractors, who discounted 11 000 mille réis on the assigned limit of cost, 4 500 000 mille réis, which was accepted.

According to the stipulated conditions, the contractors were to begin the work within six months following the date of the contract and finish it within the term of eight years after the same date.

The former condition was observed. The latter was not exactly fulfilled, on account of several accidents, in particular those that occurred on the immersion of the iron caissons for the circular parts of the heads of the break-waters. This expedient, previously adopted at Columbo, was proposed by the contractors to hasten the works and save the corresponding outlay, but did not turn out to their advantage, and experience proved that they would have served their interests better in executing without any alteration what was provided for in the plan and specification of the contract ; as they had to do after all at the head of the north breakwater. Notwithstanding, the difference was only of a few months, and the works executed after the term expired were not very important ; so that the harbor, as to the advantage taken of it, might indeed be considered ready within this term.

At all events, it seems that, as yet, no works for sea harbors of the same nature and importance have been perfected in so short a period, in a sea so much exposed to the winds of the northwest and southwest on such an extensive area, and with a section of construction so solid and complete for internal shelter.

The placing in the sea of the assorted loose rubble and the protecting artificial blocks, as well as of those with which the heads were built and also the walls on the mounds above the datum level to the quay-plane, 6 m. high, disposed in three layers that occupy all the

width of this upper structure, was mainly effected by means of the large powerful cranes, "Titans," constructed at Fives-Lille Iron Works, which did excellent service. All the stone placed with these "Titans" was brought from the quarries on the coast, or from those at San Gens, by railroads laid out for the purpose, the main supply being from the latter. A comparatively small portion of rubble from the quarries on the banks of the River Douro was put in place in the sea by means of steam hopper-barges.

The progress of the work was in general very satisfactory, excepting the losses that resulted from accidents attending the immersion of one of the iron caissons for the heads of the break-waters, and from the abandoning of another very forward in construction. In reference to the importance of the total affair, these cannot be considered very remarkable, and the contractors were on the whole very fortunate, as the damages they suffered came to much less than what, with good reasons derived from the experience of similar works, was apprehended and provided for in the computation of the amount and prices of the estimate. However, to be just, it should be acknowledged, not only that several circumstances were favorable, including the weather and the state of the sea, but also that the contractors endeavored to secure a successful result and maintained an orderly, active and economical management.

Experience, during the building of the harbor, has already confirmed, and it is thought it will continue to confirm in its use and maintenance, that the system of construction designed in the plan and specification of the contract, and which the contractors bound themselves to carry out, was appropriate to local conditions; thus contradicting the ill omens pronounced by respectable engineers of several countries before and after the works were begun.

The principal quantities of work, that according to the plans of the work and the conditions of the contract were valued and paid to the contractors are: 608 836 cu. m. of assorted loose rubble in the sea; 125 480 cu. m. of artificial blocks for the defense of these rubble masses; 3 252 cu. m. of concrete in bags in the foundations of the heads of the break-waters, 11 068 cu. m. of artificial blocks set without mortar in the heads; 9 694 cu.m. of concrete and of rubble masonry set in mortar within the caisson of the south break-water head and at the upper parts of both heads from datum to the quay-

plane level ; 131 274 cu. m. of hewn and rubble stone masonry and artificial blocks laid in mortar in the sheltering walls on the mounds and at their heads, and 18 400 cu. m. of rubble masonry with mortar in the pavement of the quays.

There were used on the mounds and quay walls of the little port of service that was constructed against the north break-water 16 840 cu. m. of artificial blocks and hewn and rubble stone masonry laid in mortar. Various ancillary works of the stoneyards, service roads, warehouses, etc., required 11 320 cu. m. of hewn and rubble stone set in mortar ; 7 689 cu. m. of dry rubble masonry ; 52 940 cu. m. of earthwork ; 700 tons of iron, and large quantities of different sorts of timber. The lengths of all the service railroads amounted to a total of 30 km. during the greatest development of the works.

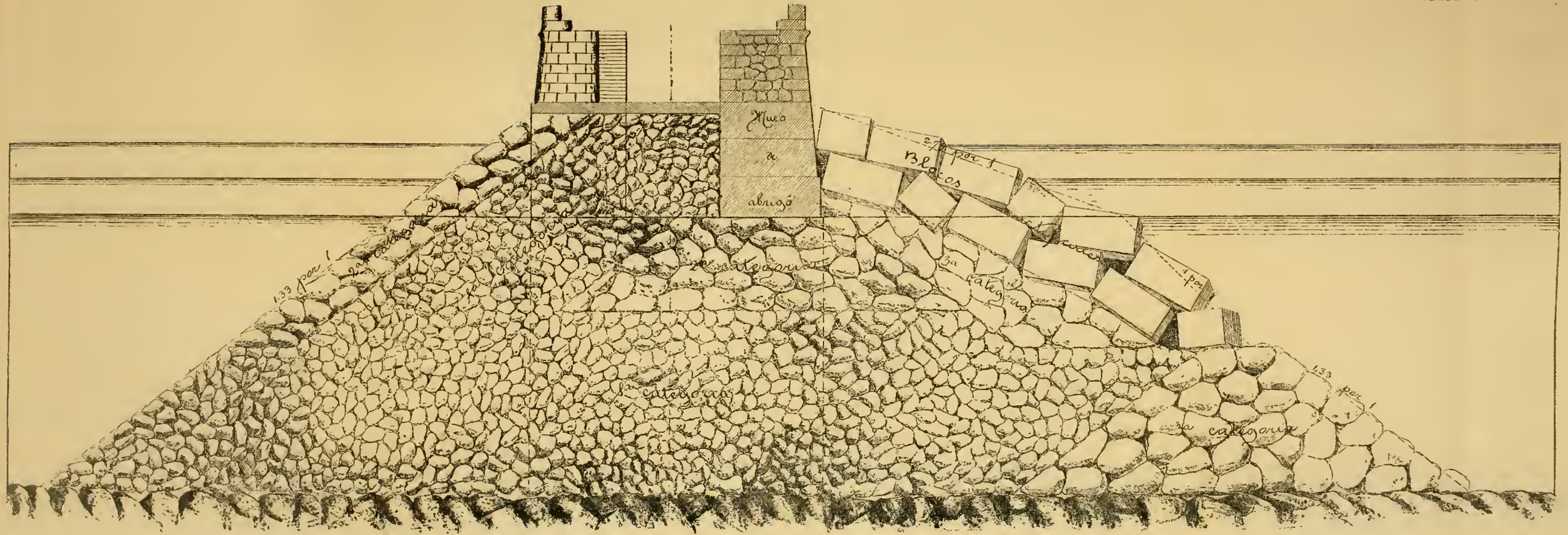
Besides two large cranes (Titans) used for building the break-waters, the contractors had two steam cranes, one of 25 000 kg. power and the other of 18 000 kg., on the construction of the small internal port ; two steam screw-jack wains (*chariots à verin*) of 60 000 kg. in the stoneyards to lift and convey the artificial blocks; as well as 25 cranes ranging from 1 500 kg. to 18 000 kg. power at the quarries and in the stoneyards. There were also seven locomotives, three for the service of the quarries and four for that in the stone-yards, as well as different fixed and movable engines in the stone-yards and workshops.

The principal floating plant employed by the contractors consisted of two large steam hopper-barges, to place loose assorted rubble in the sea, and artificial blocks at the heads of the break-waters, their service in this work being of little use ; a small steam tug and different boats for dredging at the foundations of the heads and for the conveyance of materials.

This harbor will soon have two secondary lighthouses built upon the heads of the break-waters and in the general plan of coast lighting, the construction of one of first class is also intended for its vicinity. It is also to be completed with internal works, in order to adapt it better to commercial operations, for which purpose a law has already been promulgated, but not yet put into execution.

The use that navigation has made of the harbor is already important, for, besides many coasting and fishing vessels that, in great danger in the open sea, took refuge in it, large ships have come into

VOL. XXIX, No. 608.
TRANS. AM SOC. CIV. ENGRS.
SOARES ON BUILDING OF LEIXOES HARBOR.
PLATE I.



it for shelter or for commercial operations, as well as steam-packets bound to it expressly.

This harbor is liable to deposits of sand and silt from maritime and fluvial sources, as in general all artificial and even natural harbors are; but the experience gained, up to the present, suggests that the expense of maintenance in dredging will be very moderate.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

609.

(Vol. XXIX.—July, 1893.)

THE LIMITS ATTAINABLE IN IMPROVING THE NAVIGABILITY OF RIVERS BY MEANS OF REGULATION.

By H. ENGELS, Professor of Hydraulics in the Royal Technical High School at Dresden, Germany.

Translated from the German by KENNETH ALLEN, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

When water reaches an inclined surface the effect of gravitation is to set it in motion. Thus, the water acquires a certain energy, that is, the ability to perform mechanical work.

Should the water—which, for the present, is supposed to have a continuous and uniform flow—meet with no obstruction on its way down the valley, then in a given time it will perform as much work as has been expended during that time in giving it motion. But if

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

obstructions are to be overcome on the way, a portion of this energy proportional to the resistance will be consumed, therefore measuring its amount up to that point of time. Because gravity acts continually, therefore, in the first case, in consequence of the increase in velocity with the fall, and the fact that a body with mass m moving with a velocity v possesses a capacity for work equal to $\frac{mv^2}{2}$, the energy descending would constantly increase with the increasing difference of level h from the origin of the movement, in conformity with the increase of v and according to the formula $v = \sqrt{2gh}$. In the second case a certain amount of the increased velocity will be absorbed in a given distance by the expenditure of that amount of energy required to overcome the obstructions occurring along this distance.

Our natural water-courses are in this category. In the completion of the circulation, constantly being renewed under the influence of the sun's heat upon the sloping surface of the earth, these flow toward the sea; and, since their creation, together with atmospheric influences, continually act on its ever-changing surface. The acceleration imparted to the water will be partly consumed in overcoming resistance to motion caused by adhesion and friction between the bed of the stream and the water. The adhesion and friction produce on their part internal motions through the cohesion of the water, and thus a further part of the acceleration is destroyed. Should this be just consumed over a certain distance, the water will flow for this distance with a constant velocity; if it is but partially consumed, the water at the end of the distance will have attained an increased velocity; if the acceleration is insufficient to overcome the resistance to motion, then the velocity will have become less at the end of the distance. In the last two cases the water has a varying velocity. In the first case the energy has remained constant; in the second case it is increased; in the third case it is decreased. We can also say with Lechalas (*Hydraulique Fluviale*, Paris, 1884), that in the first case the total work performed by all forces in a unit of time is *nil*. While the negative work is expended in overcoming the resistance caused by adhesion, friction and cohesion, the positive work may be taken as approximately equivalent to the product of the weight of the flowing water by the actual fall in the given distance. This is only approximate, because, as a matter of fact, the stream carries silt,

which increases in amount as the power of erosion exceeds the resistance of the bed. Sediment is the product both of the eroding action of the water and of the disintegration caused by atmospheric influences.

As the stream, which at a certain instant possesses a certain energy, attacks the bed, which is variable in its composition as well as in density of stratification, it forms its ground plan in compliance to the resistance to motion encountered, by avoiding them with a bend, *i. e.*, by changing its direction. In this manner a loss of energy occurs. The stream will, therefore, leave the bend with a less velocity than it had on entering it. In the bend itself a part of its energy must be absorbed, and that occurs here by internal motions, as is made apparent by eddies. These internal motions of the water occur as a result of the cohesion between the molecules moving with different velocities. This difference in velocity is observed to be more marked, and hence the internal movements are of greater magnitude, the nearer the molecules approach the bed of the stream.

Now, the intensity with which the molecules are driven against the stream-bed depends upon the shape of the channel, both horizontally and vertically. In a bend, the water will be driven against the concave bank by its centrifugal force, and in this way eddies with vertical axes are formed. As the water breaks against the shore it is raised, and thereby, under a correspondingly increased pressure, receives an impetus to flow back normally into the bed of the stream. These filaments of water impinge on those flowing obliquely down stream, causing the formation of other eddies with horizontal and inclined axes, which continue downward to the stream-bed and attack it in the neighborhood of the concave shore, as well as the latter itself. A change of form in the cross-section takes place by this one-sided deepening and widening. There are, therefore, two factors present which deduct a portion of the stream's energy on entering a bend—change of direction and change of form. In addition to this there is a third. The materials torn from the banks will, in proportion to their weight—*i. e.*, in case of equal specific gravity in proportion to their volume—either be drawn into the eddies by the whirling mass of water and carried off in suspension by the current, or rolled forward on the bed of the stream. This, also, is work performed which is only possible by a loss of energy.

The diminution of energy caused by bends is made evident in the first place below the bend, and, moreover, on the concave shore, by the deposition of the eroded material, the convex shore joining the concave shore down the stream. Therewith, however, the water is crowded over to the opposite shore and receives another change of direction. But while the remaining energy is entirely consumed by overcoming resistance, there will be formed no other important internal motions in crossing from one shore to the other, so that eddies working to deepen the channel will be wanting ; in other words, the bed will show here an elevation, as in part the products of the erosion in the bend above come to rest. This increased elevation acts as a bar, raises the water surface above it, and endues it with new energy, the surplus of which, when reaching the opposite shore, will be consumed by the formation of bends and pools, as in the former concave shore. We have here the formation of a serpentine channel.

Up to this point we have assumed a uniform quantity of water flowing over a bed of originally constant inclination to the horizon. We have seen that this inclination has a certain legitimate dependence upon the slope of the bed ; that, as soon as bends occur, the slope, which is at first continuous, is interrupted by pools which are formed along the concave shore.

In accordance with these principles the surface-slope is determined. The latter is the expression for the transporting power of the water. The water enters the bend with a surplus of energy and leaves it with a deficiency of the same. Above the bend, therefore, the surface-slope is greatest; in the bend it is used up in the formation of eddies. The lost fall is restored, however, by the raising of the surface of the water caused by the rising bed or dam below the bend.

Now, bearing in mind the assumption of a constant volume, and, also, that no sediment is brought into the stream from outside, when is the attainment of stability in the conformation of the channel formed by the stream itself to be expected? Evidently this is, in general, when the energy at the entrance to the concave side has become equivalent to the resistance of the bed and shore against erosion. Assuming that the stream is left to itself, equilibrium between the scouring action of the water and the resistance of the bed is only attainable by the independent diminution of the former. With a uniform discharge, such a result is only possible by a lessening of the

velocity. This depends upon the assumed uniform friction on the perimeter, and upon the size and form of the cross-section, as well as upon the fall.

Under the assumption that the shore and bed possess the same firmness, the one-sided deepening of the concave bank and its simultaneous caving in, will change its position continually. Hence, the eddies causing the deepening will not attack the same part of the bed long at a time, so that the sharpening of the curve limits the depth of scour. The length of the stream increases at the same time with an increase in curvature, that is, the relative fall of the water-surface, and hence its transporting power decreases. Under these assumptions, equilibrium must, within a certain time, be established through this play of forces.

In order to approach more nearly the truth, let us now assume that the volume of water which, until now, we have considered constant, by which perfect equilibrium may have been attained, receives an increase. The equilibrium instantly ceases. The contour of the bed has adapted itself to the action of a smaller volume of water. The action on the bed and shore must therefore increase with rising water and the additional energy. It is obvious that the places first disturbed will be those which came to rest the last, *i. e.*, the bed and shore on the concave side, assuming as before that there exists no artificial protection, and that they are therefore open to all action of the water.

When the water rises still further, the ridges of the bed separating the pools will come into motion. The bed is about to change its form, and, moreover, for such time and in such manner that it at last adapts itself to the increased scouring action of the high water. If, therefore, the high water lasts long enough, the result here must also be a condition of stability in the bed of the stream.

If the water falls again, energy is lost. If we suppose a state of equilibrium reached, and if the high water finally finds a bed which can withstand its attacks, the diminished current will be yet more powerless to alter the form and size of the bed. By the high water, too large a bed has been prepared for the lower stage. Consequently, an excess of energy is developed which is afterwards absorbed by eddies; then, in consequence and in place of this by the erosion of the bed and shore, the low water scours for itself a serpentine channel in the high-water

conduit, until such time as the excess of energy caused by the diminished fall shall have been entirely consumed.

Now, it is erroneous to suppose that in Nature the high water will last until the bed has become stable under its action. On the contrary, during the state of high water, just because it does not last long enough, the whole bed is in motion, the deposits assuming different velocities forward depending on their size, form and weight. The heaviest slide or roll along the bottom; the lighter ones are carried in suspension down the valley.

With falling water the energy decreases. Then the scouring of the bed ceases, as a greater force is necessary to tear the material loose from its resting place than is required to transport the material already loosened. The stream now carries sediment only. Gradually, with the falling water, it loses this power also, and the sediment comes to rest. The place of deposit is usually independent of the shape of the stream. At a certain instant, when the water has fallen so far that it has not the required energy, the sediment falls, or remains where it happens to be at the time.

Here the fact is to be noted, that a separation of the sediment according to its weight takes place in such a way that, where there is the strongest current, the heaviest material is set in motion; while in places where there is less current, especially where free from eddies, only the lighter material is set in motion. With falling water, therefore, it is not always the heaviest sediment that is deposited, but, as, for example, where both convex and concave banks occur, both light and heavy matter at the same time. But, while all movement of sediment ceases very soon on the convex side, there occurs on the concave side, on account of internal motions, a transport of such lighter material as has already come to rest on the convex side. Only when this material is carried by the eddies from the concave to the neighboring convex side does sedimentation take place. The new condition of repose in the stream-bed occurs only with the cessation of all motion in the material on the concave side. Then the stream, which at high water has usually a more direct course, and therefore a greater and correspondingly less changeable fall, has been transformed into a low-water stream with sharper curves, and hence more variable fall, and generally (on account of the increased length of the stream) of diminished fall.

If a tributary enters the stream at any point, we have to deal with two reaches of the river of different nature, divided by the point of confluence. The lower reach receives an addition, both in the volume of water and also of eroded mineral matter. The energy at the confluence must necessarily be changed, and will be greater or less, according as the tributary carries respectively more water or more mineral matter. In the first case, the surplus energy is dissipated by a scouring out of the bed and lowering of the surface, and a reduction of the slope below the point of intersection occurs which is connected with the slope above by a line of greater slope. In the second case, the preponderance of mineral matter brought from the tributary produces an increased resistance which the existing energy is insufficient to overcome. This can only be effected by a rise of the water above, by which the greater fall necessary to produce the moving power is brought about. The line of slope shows a rise at the mouth of the tributary.

There is less necessity for fall with an increasing volume of water, assuming a similar construction of the bed. In reality the volume is increased only spasmodically in consequence of additions from tributaries, but it is constantly augmented by the ground water. This plays an important part, at least so long as the ground water entering at the sides is under a higher pressure than that in the channel. The pressure of the latter is measured by a column of water with a height equal to the distance from the bed of the stream to the surface, and hence it decreases with a fall of the water. In general, therefore, this subterranean feeding will take place chiefly during low water ; while, on the contrary, during a high stage, when the stream is under greater pressure, it is forced into the subsoil at the bottom and sides. This phenomenon is in so far important, as by the coming forth of the ground water during a lower stage the stability of the bed is lessened, but is increased at high water. In the first case, the bed will become loosened and its mobility increased ; in the last case it is lessened. By the motion of the molecules from top to bottom, or from bottom to top, fresh disturbances of the flow—new energy-consuming eddies—are produced, a factor entirely passed over in previous "rational theories" of the motion of water in natural water-courses !

The foregoing explanation demonstrates without further argument that if the bed of a stream for the entire distance were composed of

similar material, the slope of the surface would decrease at such a stage as would render possible the feeding of the stream by ground water, *i. e.*, generally, during low water. Under these conditions, however, a continual alternation of greater and lesser slope exists in reality, by reason of this constantly decreasing fall, corresponding to the pools and bars; greater and lesser depths following and limiting one another caused by the bends. Evidently, this change will be more marked the lower the water, and, *vice versa*, it will be less so the higher the water rises. But even if we suppose that the stream had to overcome similar material for its entire length, a decrease of slope after any continuous bend would be quite impossible with the discharge of tributaries, while, as we have seen, every such mouth must necessarily cause a change of slope. This impossibility is the more marked as our water-courses flow in beds whose inclination, on the whole, depends upon the uneven and lawless slope of the earth's surface, in beds which present a very variable resistance, on account of the materials forming them. We speak here without reference to those places where the action of erosion is not yet complete, where therefore the bed is not formed by alluvial deposits brought to rest. We find such places, for example, where solid ledges of rock crossing the stream produce a raising of the bed, which, it is true, must eventually disappear through the eroding action of the water, but this will not occur for the periods of time practically in question. Such places always produce a break in the slope, and, moreover, a reduction above and an increase below.

Now, we usually find toward the mouth a reduction in the volume of deposit, so that, for this reason, the necessity of a fall decreases towards the mouth. But this reduced deposit undergoes just as much change of place as the surface-slope of the stream. The opinion is maintained by the writer that in finished reaches of rivers only a small part of the deposits carried down stream reaches the mouth; that, rather, the greater part remains forever motionless in the bed of the river at a comparatively short distance from its original location. Therefore, there is but a small part of the stony deposit present in the region at the mouth of completely finished rivers, which is not the product of the continuous attrition which the loose material, coming into the river above, receives on its way down stream. The greatest portion of these deposits is formed from, and corresponds in

size exactly to, the component parts of the diluvial and alluvial deposits which have been formed in previous times, and which form the depths crossed by the current. It is not in opposition to this theory that our large rivers annually carry immense quantities of mud and fine sand into the sea. Every loose particle which comes into the stream suffers a rubbing off, if ever so slight, in its motion down stream, the product of which forms a part of this mud. Besides this, the rain and high water flowing from the vegetable mold bring mud to the streams continually, which is carried in suspension to the sea. Only in streams or portions of streams in which the work of erosion is not yet fully developed, has the energy not yet been brought into equilibrium with the resistance of the bed. On account of the excessive fall, the energy is in preponderance; the desired equilibrium can only be attained by lessening the fall, *i. e.*, through a progressive scouring out of the bed, increasing from below upward. The loosened deposits are evidently transported for the whole distance where the whole bed is in a state of erosion, and only come to rest below the same. The deposits form a ridge down stream in the bed of the reach, which is made apparent by a backing up of the water, *i. e.*, a lessening of the slope up stream. Therefore, we have in succession three characteristic reaches in the course of the stream. In the first place, an upper one in which erosion is not yet complete, where transportation exceeds subsidence; a middle neutral reach where transportation equals subsidence, and finally, the lowest, where subsidence is greater than transportation. If, now, there is always a sufficient volume of water for the formation or maintenance of a certain energy, an uninterrupted transportation of deposit in the two upper reaches will occur. In consequence of the erosion of the bed in the upper reach, this transportation must continually diminish, as in connection with the raising of the bed below, which occurs at the same time, a lessening of the slope takes place, which is checked as soon as the resistance of the bed becomes equal to the transporting power developed by the fall.

In completed reaches of the stream, a condition of equilibrium exists which is temporarily disturbed only at high water; in the unfinished ones that condition is approximately reached. In the first case, the river flows on its own alluvion; in the latter, on a bed which is always deepening. Here the deposits on the bed suffer a change of position, which occurs within limited bounds of both time and space;

only that portion of the deposits which forms the upper stratum of the bed receives anew an impetus down stream at every high water. It remains at rest, therefore, between every two periods of high water, and hence a long interval of time is required before this portion reaches the mouth of the stream. Hence, this portion yields reluctantly to the eroding action of the water and the disintegration by attrition caused by mutual contact during transportation. In unfinished reaches of rivers all sediment that is set in motion must traverse the entire distance in which erosion occurs. It naturally undergoes a gradual decrease. But it must be emphasized that this law of the "wandering" of deposits and the lessening of it (when extended to all deposits) is true only of unfinished stretches of river. It should not be generalized of finished rivers, as is usually the custom at present, and against which G. Hagen has already raised an important protest. The deposits occurring in finished water-courses are but partially products by attrition of deposits formed in the upper part of the stream. They are, for the most part, products of the crumbling away of the banks of the same part of the stream in which they are found. The fact that both sediment and material rolled along the bottom are actually found in the lower portions would seem to contradict this, but these are doubtless brought into the stream at points far above the stretch undergoing erosion.

It is unfortunate that no reliable observations have been made which could help solve the very important questions relating to the origin, the course and the final resting place of deposits. The impossibility of following the silt with the eye during its wanderings prevents the observation and investigation of these transactions in Nature. It can only be confirmed by such observation as that, for example, a bank of deposit either retains its position permanently, or after a certain time has disappeared from a given place. It is only a supposition, not yet proved, that the bank of deposit newly formed down stream is formed of the same material as that which has meanwhile disappeared, having been loosened by the action of the water; that, in other words, one and the same bank has changed its place. In order to make this last an incontestable fact, one would have to bring forward proof that the deposits forming the second bank are indeed the same as those composing the first. This hint is all that is necessary to show the impossibility of a positive demonstration in Nature.

Therefore, nothing remains but to experiment on a small scale in order to throw light upon the phenomena. For this purpose the author has built a flume of zinc in the hydraulic laboratory of the Technical High School of Dresden. Clean sand of uniform size, but of various characteristic colors, was put into this flume in such a manner that colored alternated with colorless sections, the location of each of which was accurately established by measurement before being put in. A certain volume of water taken from the city supply was led through the flume in a steady stream, and the sand was set in motion by a certain inclination of the flume. It then became apparent that a movement of the sand along the whole distance occurred only when, by a comparatively great inclination of the flume, erosion of the sandbed was effected. If the flume was given a smaller slope with a certain quantity of water and therefore a certain energy, only eddies were formed along the concave shore, which, as was mentioned in the beginning, set bed and shore in as tate of attack. The loosened grains of sand acquired but a slight motion down stream ; they were precipitated, forming ridges which crossed the bed in arcs closing down stream, and in the shape of banks which were formed in the convex parts. After awhile, complete repose was reached in the sandbed—a sign that equilibrium between the bed and the forces of the stream was reached. More water was now introduced. The eddies in the pools again showed their effect in loosening and transporting the sand. The pools and inroads on the banks became deeper and wider; the loosened material came to rest, rolling over and then covering the deposits of the lower stage, and a new state of equilibrium was established. As the volume of water was diminished, the serpentine formation of the low-water bed inside the more direct high-water channel took place. But the contour of the channel had already conformed itself to the energy of the high water, so that when a greater quantity of water was again admitted, the effect of the increased energy was only apparent in the obliteration of the low-water formation by a slight and evanescent change of place in a small portion of the upper layers.

Numerous and careful experiments confirmed the fact that the characteristic traits of "finished streams are, that the surface-slope is in equilibrium with the shape and size of the bed, so that usually its form is in a state of rest, out of which, however, it is aroused at times when by a higher stage, a temporary disturbance of the equilib-

rium occurs, in consequence of the increased flow of water. In finished streams the moving power of the water undergoes no alteration with the same quantity of water, when disintegration is impeded by protecting the banks. With unfinished reaches the moving power constantly decreases with the steady decrease of slope.

When there arises the problem of regulating a river in the interests of navigation, *i. e.*, subjecting it to constructive treatment, without a loss of its natural characteristics, one must from the beginning preclude from such regulation the "unfinished" reaches last characterized. Regulation can only be successful in the case of "finished" reaches. Unfinished reaches can only be changed to a state of permanency with a stable bed, by canalization. A well-known example of an "unfinished" reach is the upper Rhine from Basle to Mannheim. Here the profile corresponding to a condition of equilibrium is not attained, as is evident by the ceaseless and progressive lowering of the bed. Hence, we find here a constant transportation of sediment down stream. It is true that erosion has been artificially developed by the marked shortening of the stream, which formerly had many windings. Only when the deepening of the bed has ceased, can further regulation lead to improved navigability.

Navigation has to contend with two principal evils: sharp bends, and lack of depth in the channels. We have explained how they influence and depend upon each other. We have seen that these irregularities, the removal or at least the alleviation of which appears necessary in the interests of navigation, are indicated by a variation in the surface-slope. As we regulate the latter, we regulate the stream itself. On the whole, however, one cannot alter the fall between given limits, as this has been produced in such a manner as to correspond to the natural features of the stream. One can only remove the local irregularities in the fall, *i. e.*, effect a local adjustment of the surface slope within these limits. As the irregularities in the fall are a maximum at the lowest stage of water, we may doubtless consider them as caused by the latter. If the slope is adjusted for low water, then, in a uniform and rationally formed channel, this will also obtain with higher stages of water.

Before we can consider the treatment of a low-water channel however, the "finishing" of that part of the channel above the low-water line must be completed—the conditions of the river-bed must have

adapted themselves to the change of energy caused by this finishing. The considerations upon which this finishing depends are—entirely in the interests of the regulation of rivers—the following :

As the river has an excess of energy during high water, everything is to be avoided in finishing the high-water profile, which would produce an increase of energy. A change of form into narrower and deeper ones of such natural high-water channels—which, as they have adapted themselves to the energy of high water, suffer but slight changes during that stage—is always connected with unfortunate results; because, on account of the increased energy, there occurs an increased scour of the bed; and because, therefore, large quantities of sediment are set in motion. It is true that in this way an energetic deepening of the channel takes place during high water, but after the high water, the sediment, which was in motion, settles, forming again, if not increasing, the irregularities of the bed. But navigation has always sufficient depth at high water ; therefore, the deepening of the channel is of no value, being temporary and occurring only at high water. Where, therefore, it is necessary to build high-water dikes in the interest of agriculture, the river may be expected to show changes after the high stage ; they are the inevitable and natural results of the excessive increase of energy at high water.

Every water-surface will find solid banks, at least at the places where the latter are attacked, in consequence of the formation of the ground plan of the stream. The next desideratum, therefore, is to reinforce the banks at the high water-line, or to construct new banks, strong and high. Between high and mean water, the river will usually overflow its banks, so that, to a certain height above mean water, when it is more or less full, the surfaces of its projections determine, for the time being, the lines of the shore. As strong currents cannot be formed on account of the slight depth of water over the projections of the shore, the requisite protection usually consists in a covering of grass and other plants. Only where grasses, etc., do not flourish is it necessary to protect the shore by traverses, which should be finished off at the level of the projection of the shore.

Where a stream is left to itself, the mean-water shore is formed by the natural boundaries of the true channel. Where a stream is to be regulated, we must endeavor to produce a uniform channel, where possible, by obstructing the subsidiary channels, so that for mean

water it will be impossible to avoid building new artificial banks at certain places. These must be constructed by strengthening in lines which lead to a uniform channel, and which, moreover, are connected with the existing natural lines where possible, so that they will be insured against disintegration, where such a thing is to be expected on account of the ground-plan of the channel. These lines are also dependent upon the relative distance apart to be given the banks during mean water.

As but one definite relation exists between the discharge of water, the size and shape of the cross-section, the surface-slope and the character of the bed, for the condition of equilibrium; and as this relation cannot be determined theoretically because of our ignorance of the laws controlling the interdependence of the very intricate motions of flowing water, especially as in a state of Nature we have always to deal with a variable velocity produced principally by internal motions; therefore, empirical methods are here best, saving one from more disappointments than the most profound speculation. "All theories assume an impossible stream," says Lechalas. Weber von Ebenhof expresses in a most apt way what is to be done: "The correctness of the cross-section is controlled by the true relation between the width of the channel and the depth of water in it; a relation which one learns best from the careful study of the natural profiles of unregulated rivers."

We may expect profiles to remain stable if we always employ good natural profiles on reaches of similar regimen, only when the original conditions under which they have been formed and maintained are everywhere the same.

The reaches which are well formed under the influence of the stream left to itself, and which remain well formed, always lie in such a manner that they are traversed by high and mean water in exactly the same direction. This is only possible when that part of the formation which is above high water is uniformly protected, preventing the breaking through of the banks at high water; or where the water breaking through at a high stage does not deviate from the direction of the mean water current. Such a section occurs usually at the apex of the concave bank and in such straight reaches as lie in the same direction as the current of the eroding high water. In all such reaches the operations of the high and mean water support each other; they are em-

phatically reaches of erosion in so far as the channel has, on account of this co-operation, buried itself comparatively deep They are, for the most part, therefore, reaches with a relatively weak fall which is smaller than the adjusted fall which is to be attained at that place under the most favorable conditions. Above and below that reach which has been well formed by Nature, breaks in the slope are found. When we construct uniformly a mean-water width peculiar to this reach on reaches of like regimen—*e. g.*, from confluence to confluence —the reach so treated will receive a certain degree of improvement, for as it becomes narrower an increase in velocity obtains. There results an unbalanced increase of energy, and, in consequence, a temporary disturbance of the equilibrium between the eroding power of the water and the resistance of the bed, which will only cease when the energy is reduced to its original value. But this is only possible through the scouring and deepening of the bed, as in only that way is a diminution in the fall produced, corresponding to the lessened necessity for fall on account of the more propitious profile formed, which we now find. A reduction of the fall can only be attained by a lowering of the up-stream water-surface. If the regulated reach joins one naturally well formed below the latter, then the fall of the natural reach will necessarily increase, and there will be also in the regulated section, as a result of regulation, a lowering of the water-surface and a reduction of depth. If the regulated reach lie above the typical natural reach, the original conditions under which the latter has been formed will also be changed. The fall in the regulated reach will be reduced by a lowering of the surface, and the water will enter the natural reach with an energy less than that existing previously. The internal movements causing a deepening of the bed are developed less in the natural reach than before ; the deposits, loosened by the scouring of the bed in the regulated reach, come partly to rest in the natural reach, raising the surface of the bed. This causes a raising of the water-surface in the natural reach above, and an increase in the relative fall below.

It is evident that we cannot develop good natural profiles uniformly by regulation which consists in entirely restricting the width. The ultimate effect of such regulation is, and can only be, that the line of slope, which was at first broken, is changed to one of more uniform slope. At the same time the reaches well formed by Nature necessarily undergo a diminution of depth. The depth to be attained will, there-

fore, always be less than with such good, natural profiles. We may approximately determine beforehand the depths to be attained during mean water, by careful and numerous measurements of the cross-section and leveling of the water-surface, and then determining the difference between the new line of slope which obliterates the irregularities in the fall and the adjusted bed. These operations are only admissible and sufficient for such reaches as are traversed at high water in a direction parallel to that at mean water. Where the two directions deviate from one another—and this is the case for all passages from one shore to the other—a restriction of the width at the height of mean water will not result in any marked deepening, because the passages crossing at high water would detrimentally affect their action at mean water. This is different in the concave bends. Here, the mean and high water assist each other and the deepening is permanent. The difference between the excessive depths in the concave bends and the shoals in the passage is greater than before. The variations in the fall of a serpentine stream remain, in general, unchanged. At all events, the full effect of the increased depth is of small account, because the bed and surface of the water are lowered simultaneously, so that the gain in depth is only the difference between these lowerings, which under certain conditions may equal zero.

The establishment of a narrower uniform mean-water bed gives the advance flood an especial advantage, as the water cuts out a deeper channel. In the more deeply cut channel, however, the irregularities in the slope at low water remain, in general, the same as before. Therefore, completion of regulation only by restricting the width of the mean-water bed will not furnish that degree of navigability which may be attained.

When, on the other hand, the advocates of this system point to the results, substantiated by figures, which have been actually achieved in many rivers, we have to say that these results were quite inevitable, because they selected for regulation, rivers wholly uncontrolled, with many islands, branches, etc., and because in place of the channel, which was split up into many branches, they provided a uniform conduit by the obstruction of the branches, in which, naturally, a much greater depth must obtain than in the original stream. If, however, a river is regulated in this way, a decided increase in the depth by further restriction of the width cannot be brought about. The wilder a stream

is, the easier it is to accomplish great results by regulation with restriction of width; but the more a uniform water-course is formed by building out the banks and obstructing the side channels, the harder it is to attain a greater depth by a further application of the system of the restriction of width. It is easier to make a wild river double its depth than to deepen a regulated river by a few centimeters.

The mean-water shores extend into the stream-bed either with a comparatively uniform slope—this being the case with concave shores which should be built out with the flattest possible slope—or, at the convex shores, a flat bed of sediment is deposited, either directly or indirectly, at a comparatively slight depth. As the upper surfaces of convex shores are exposed to the injurious cross-currents of the higher floods, they are to be reinforced by traverses whose strengthened tops do not rise above the surface at the highest point, but project in a gentle and uniform slope out into the stream-bed. These traverses, which are to be firmly connected at the land end with the mean-water shore, bound the low-water shore, which follows here the natural ground-plan of the beds of deposit, at low-water level; but at the same time, the irregular boundaries of the latter are to be evened off by the most easy and regular curves. Reinforcement of the steep concave shores completes the protection of the shore in the curve. The low-water width, which is here present and protected, is to be completed uniformly. A further restriction of the width of the low-water bed, assuming that such would not hinder navigation, would lead to a double profile for mean water, a form not assumed by good natural mean-water profiles, which latter should be striven for, and reached under favorable conditions.

The bottom of the channel will still show a succession of pools and shoals corresponding to the conformation of the ground plan. We have only procured a channel as uniform as possible whose shores are protected against the attacks of floods rising above low water. The real work of regulation is now to be undertaken, the removal of the irregularities in the fall. Here we must establish an increase of fall over the pools, and at the same time a decrease of the same at the passages over the bars below the pools. This is to effect a greater depth at the bars so that the inherent energy of the flowing water will be retained as much as possible while passing the work-consuming pools. Three factors are met in the bends which absorb energy, as explained

in the beginning: (1) change of direction; (2) change of form, and, moreover, an enlargement of the cross-section, and (3) the loosening and transport of deposits. The change in direction must, in general, be retained. By flattening the curves, which are too sharp, the effect of (1) can be diminished by a small amount. There remain, therefore, the artificial influences brought to bear on (2) and (3). So far as the former is concerned, the profile, which is deepened and widened on one side, is to be changed to a flatter one of more symmetrical form by raising the bottom of the channel. But, in order to render this new profile permanent, it is necessary to make the new bed firm. Both are to be attained by submerged dykes, which must cross the bed at alternate intervals to be empirically determined, on the one side over to the traverses projecting with a gentle inclination from the convex shore, and on the other side connected to the steep concave shore at low-water level by a flat slope. The water-surface will be raised in the pools by this raising of the bed and change of form in the cross-section. As this raising of the water-surface approaches the original surface-line upstream in an asymptote, as in a back-water curve, the depth of the water will, at the same time, be increased with the reduction of the excessive fall on the bar above. This increase in depth is still further augmented by the water emerging from the bend, this being possessed of a greater energy than before, because of an increased slope, attacking the bar in the bed of the channel down stream, and so far lowering it that a new condition of equilibrium is formed corresponding to the increase of energy. Should the strength of the current be insufficient for this, we can remove the bars by dredging the material without danger of its reappearing, as the cause—the energy-consuming work of the pools—has ceased to act. The loosened deposits are caught in the ridges of the next pool below, thus turning it into land.

With reference to the increase of depth, we can predict, if only approximately, the result to be expected under the most favorable conditions, by starting from the new line of slope which evens off the irregular low-water line of surface-slope and seeking the difference between it and the corresponding adjusted line of the longitudinal profile of the bed at the thalweg. The latter also determines the height of the bars. Mathematically, we estimate the depth d to be attained in the following manner:

Assuming the two known equations—

$$Q = w\,d\,v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$v = k\sqrt{d\,i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which d and v (velocity) are unknown, Q (volume of water) is to be determined by measurement, w is the natural low-water width of the surface in the required mean-water bed, to be measured in the apex of the bend; i is the adjusted rate of fall attainable. It suffices to determine k approximately from the equation—

$$k = \frac{v}{\sqrt{d\,i}}$$

in which we give a value to the right-hand member to be established by measurement in the low-water channel existing in good natural reaches.

From (1) and (2) we obtain the equation—

$$d = \left(\frac{Q}{w\,k\sqrt{i}}\right)^{\frac{2}{3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This equation shows that d decreases in the pools, because the slope i increases while w is unchanged; further, that d increases on the summits of the passages as a decrease of i takes place, in consequence of the uniform establishment of the natural low-water width in the apex of the bend, and therefore a better concentration of the water, and also from a decrease of w.

On the basis of the foregoing discussion, the answer to the question forming the theme is given in the following conclusions:

(1) Only rivers or long reaches of rivers in which natural erosion is fully developed are adapted to regulation. The navigability of unfinished rivers, yet in a state of erosion, can be improved with permanent results only by canalization.

(2) The most that can be accomplished by regulation is the desired adjustment of the slope of the low-water line, and this only on reaches of uniform regimen and uniform characteristics.

(3) This feasible adjustment of the slope, to be accomplished when the conditions are most favorable, can only be established and brought about by constructive measures after formation of that part of the channel which rises above low water is completed; after the conditions of the bed have adapted themselves to the change of energy caused by the formation of the mean and high water bed—in other words, after the erosion caused by this formation has come to rest.

(4) To secure the establishment and permanent preservation of the adjustment of slope, the irregularities of the bed in the longitudinal and transverse profiles are to be adjusted after reinforcing the low-water shore, and the bed is to be strengthened where attacked by the water on account of the ground plan of the channel. Restriction of width alone will not bring about that degree of navigability which may be attained.

(5) The maximum depth of water to be maintained during low water is then determined by equations (1), (2) and (3).

The writer has thus reached the conclusion of his demonstration. Those who, on account of the title, have counted on an exposition equipped with great mathematical and speculative apparatus, who have expected that the question propounded would be solved in an abstract, theoretical manner, will be disappointed. But it can be assumed that there are not many such, that the majority will acknowledge without further question the truth conveyed in the words already quoted: "All theories assume an impossible stream." The writer's only wish is to show that under certain premises, but only under such, an answer to the question propounded is possible. He is well aware, however, that with regard to this indispensable hypothesis, it is in Nature—in practice—never to be entirely reckoned on. Thus, for example, complete stability of the bed will never obtain during high water; it will not obtain so long as tributaries which are in a state of erosion discharge silt into the main stream, so long as disintegration of the banks occur. Even the introduction of suspended particles of the soil after every heavy rain and every flood will make absolute stability of the bed unattainable. We can, therefore, simply ascertain approximate values.

Furthermore, it is well known that in practice many considerations, for the most part reasonable, render the rational construction of a channel unfeasible. We can rarely remove irregular dikes running beside the stream, or injudicious and obstructing habitations. We must then pursue the best course possible, *i. e.*, in spite of such circumstances, we must regulate only the low-water bed and endeavor to keep it in good condition by means of maintenance, such as dredging.

The subject was suggested by the transactions of the Third International Congress of Inland Navigation at Frankfort-on-the-Main in 1888, at which—conformably to a motion of Professor Schlichting, of Berlin—

the necessity of attempting to establish the degree of navigability of water-courses which may be attained, was unanimously acknowledged. It is very greatly to Professor Schlichting's credit to have brought this necessity into prominence. G. Hagen has declared in his book on constructive hydraulics, that there are no bounds to the demands by the public who make use of the water-ways for the navigability of rivers; while the natural formation of rivers entirely prevents the extension of their navigability beyond certain limits. Certainly the complaints of ship-owners of the poor character of our water-courses will not cease, until hydraulic researches have determined what degree of navigability can be attained by regulation under the most favorable circumstances.

If we wish to attain a greater depth than is possible by regulation, the only method is by canalization. Let us hope that a further exchange of ideas and a further clearing up of the question may result from the foregoing discussion, which exchange would appear the more to be desired the more it is recognized in what difficulties we are involved on all sides wherever this question arises.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

610.

(Vol. XXIX.—July, 1893.)

THE IMPROVEMENT OF HARBORS ON THE SOUTH ATLANTIC COAST OF THE UNITED STATES.

By WILLIAM MURRAY BLACK, Captain, Corps of Engineers, U. S. A., M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the following paper the writer has attempted to show the general conditions of the coast, the forces acting and their effects, and then to give a history of a few of the more advanced works, with remarks on such engineering features as he thought of general interest. The paper is, from its nature, more or less a compilation, and the

NOTE.—In his studies on the subject, the writer has received much aid from the following books: Harcourt's "Harbors and Docks," Stevenson's "Construction of Harbors," Mitchell's "Reclamation of Tide Lands" and "Tides and Tidal Phenomena," Gilbert's "Topographic Features of Lake Shores," Bache's 'Atlantic Coast Tides," and, most of all, from the reports of the various officers and assistants of the Corps of Engineers, U. S. A., published in the annual reports of the Chief of Engineers. To all of these authors he desires to express his indebtedness.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

writer has quoted freely from published works, preferring to give the exact words of the authority when possible.

The southeast Atlantic Coast harbors of the United States belong to the troublesome "harbors on a sandy coast" which have been so long a cause of worry to engineers and governments, and which so often obstinately refuse to "stay put" after much money and time has been spent on their improvement. Maintained and destroyed by the same power, the ever-restless sea, their formation and maintenance depend on so nice an understanding of the forces at work, and so nice an adjustment and control of these forces, that it is not strange that disappointment has frequently followed so much painful effort.

The creating and destroying forces are the sea and the winds; their instrument, the sand. These are never at rest, and it is the problem of the engineer so to control and guide them as to cause them to build the protecting beach, or to deepen the desired channel, and having finished their work, to pass harmlessly by the harbor they have formed.

The winds act on the sand directly and through the medium of the sea. Their direct action is to transport vast quantities of sand over the level surface of the beach, or to roll along the dunes already formed. By sand catches, sand fences and plantations of beach grass this movement can be controlled and turned to useful ends. On a dry beach during a brisk gale, the whole surface is in motion. On the Florida coast the sand moves like drifting snow, with a depth of 4 to 8 ins. A properly constructed sand catch on that coast can form a dune 10 ft. high in a single year. The resultant movement is in the direction of the prevailing gales. It would be difficult to estimate how great a factor in the formation of the bars across the openings in the coast line this movement is, but its effect must be very large.

The indirect action of the wind on the sand beach is through the waves. The coming of a gale is frequently heralded 36 hours in advance by heavy rollers. During the gale, the wave height is reduced; but the surface velocity of the water (and its erosive action) is greatly increased. After the gale has passed, the waves again become higher and make up in battering power for the loss of velocity.

Wave crests approach a coast in lines perpendicular to the direction of the wind. As each wave feels the bottom, its advance is retarded. The line of wave crest which originally had approached

the coast diagonally, swings around and finally breaks on the beach in a line more nearly parallel to it.

Wave form, velocity and energy have long been studied, but the greater portions of the investigations have been made under conditions radically different from those prevailing on our sandy coasts and are of but little immediate practical use there. According to Scott-Russell and other authorities, the form of oscillating waves is that of a prolate cycloid, which changes to a common cycloid just before breaking. "Hagen * * * * showed that the line which unites points which are in the same phase of a revolution is a prolate cycloid, which becomes more prolate as the depth increases, and at the surface approaches a common cycloid. Weber Brothers and Rankine state the orbit of each particle to be an ellipse, while Froude, Scott-Russell, Hagen and Gerstner state that this orbit is a circle. When the wave enters shallow water the general opinion seems to be that the orbit is always elliptical."* According to Stevenson the height of a wave crest above the mean level of the water is two-thirds of the wave height from hollow to crest, and waves break when they enter water whose mean depth is from once to twice the wave height, breaking earlier when the bottom shoals rapidly than when the slope is gradual. Stevenson gives much interesting data on the relation of fetch to wave height, etc., but with the very gentle slope of the bottom along our southern coast, the storm waves of the Atlantic are broken and reformed long before the beach line is reached. He gives the velocity of the longest waves on the Atlantic Ocean as 115 ft. per second, and of ordinary storm waves as 50 to 60 ft. per second.

Of greater immediate value in the present discussion are the investigations of Lt. D. D. Gaillard, Corps of Engineers, on the force of waves on the Florida coast. Lieut. Gaillard's conclusions may be condensed as follows: Waves with the form of a common cycloid have an energy in foot-pounds for each foot in length measured along the crest, and for that portion above a horizontal plane tangent to the hollow, equal to $6.3\ h^3$, in which h is the height in feet from hollow to crest. The application of this formula is expressly limited, and is useful mainly in comparing the relative exposure of two places where shoal water extends for some distance seawards and where the fetch of the waves is practically unlimited.

In shallow water, immediately before breaking, for waves varying

* Lt. Gaillard, Rep. Chf. of Engrs., 1889-II-1319.

in height from 2 ins. to 7 ft. (hollow to crest), the observed relation between wave height and velocity is expressed approximately by the formula $h = .08242\ x^{\frac{3}{2}}$, in which h is the height, and x the velocity in feet per second.

These waves broke when they arrived at depths, which, when the water was undisturbed, were from $0.72\ h$ to $2\ h$. For the great majority, h equaled d (depth of undisturbed water) at breaking. For a given locality the variation in the ratio of d to h seemed to be caused by the direction and force of the wind. A strong wind in the direction of wave motion made $d = 1.25\ h$. A strong contrary wind made $d = 0.72\ h$. With no wind and a uniform bottom with a slope of 1 on 100, d equaled h. With a slope of 1 on 12, d sometimes equaled $2\ h$.

Observations on waves varying in height from $2\frac{1}{2}$ to 6 ft. showed that the height of wave crest above the mean (undisturbed) water surface varied between $0.67\ h$ and $.89\ h$, with a mean value of $0.76\ h$. A gently sloping bottom or an opposing wind increased the height of crest; a steep slope or a favoring wind decreased it.

"Considering only a well-defined wave, breaking in water of a depth equal to its height from hollow to crest, the maximum effect (recorded by dynamometer readings) was found at a distance above the water surface equal to about $\frac{1}{10}$ of the wave height, from which point it decreased to zero at a distance above the water surface equal to about one-fourth of the wave height."*

In all this discussion the distinction between velocity of wave propagation and the velocity of translation of the particles of water in the wave must be kept clear. McAlpine showed by experiments with a tank of fresh water that when water was added suddenly at one end, the effect was felt at the other end by a wave long before the actual movement of translation was transmitted to the water there. The velocity of wave propagation was to the velocity of transfer of the water as 1 is to .09. This is constantly seen in our tidal rivers. In the Savannah River the rate of propagation of the flood tidal wave varies from 12 to 16 miles per hour, and the maximum velocity of the flood current is 1.4 miles per hour.

The wave which in a deep sea is a simple undulation, excepting where its surface is thrown onward by the wind, changes in shape as the shallow water is entered, and the energy of undulation is transformed, more or less completely, into a force of translation, according

* Lt. Gaillard, Rep. Chf. of Engrs., 1891-III-1637.

as the entire wave, or only a portion, breaks. The final break occurs where the incoming wave meets the rapid first backflow of its predecessor from the beach.

"It is a familiar fact that waves running over shallow ground acquire a real motion of translation. The passing of a wave, as felt by divers standing upon the bottom, is a sudden jerk toward the coast. The water that would thus pile up against the shore is carried back into the ocean by a gentle and continued current. The movement toward the land is in very short, but very rapid, dashes, while the return is more gentle and steady. In this contrast of velocities between the onset and the retreat of the sea lies, I think, the true cause of the accumulations upon the coast and the tendency of heavy bodies, like the coal from steamers, etc., to come on shore. When we consider that the work done is proportional to the square of the velocity and that the weight that may be moved by running water varies with the sixth power of the velocity, we certainly may expect the changes along the coast to reflect rather the action of rushing waves than feeble currents."*

A heavy gale heaps up the waters on the lee shore when the wind and wave action is oblique to the coast line. This heaping up of the water gives rise to a current parallel to the beach and close in shore, generally within the first line of breakers.

The effect on the sand may now be noted. In experiments made during the construction of the Brooklyn Bridge, Mr. Collingwood found that when sand was thoroughly mixed with the water, 40% in bulk was carried when the velocity exceeded about 22 ins. per second; when the velocity was less, a deposit was made. Colonel Elliot, in his report on the improvement of the Harbor of Nantucket, assumes that a velocity of 1.25 ft. per second is sufficient to produce a scour on a bottom of gravel and sand, and quotes the following authorities: Debauve, 0.5 to 1 ft. per second; Login, 0.67 to 1 ft. per second; Weisbach, 1.25 ft. per second. The writer has seen a bank of packed fine sand stand without loss under a velocity of 3 ft. per second, but melt away when that current was accompanied by the slightest wave motion. It may be accepted that sand in suspension may be transported by a current too feeble in velocity to lift it from its bed.

As the successive waves approach the shore, there is a slight and continuous motion of sand beneath them; and this sand, lifted by the waves, is moved shoreward by the breakers, and during on-shore gales, parallel to the coast by the littoral current induced as previously

* Mitchell, "Reclamation of Tide Lands."

described by storm action. Arrived at the steep slope of the beach, the wave breaks with great force, and its water, loaded with sand, rushes up the slope, approximately in the direction of the wave approach. A portion of the load of sand is deposited at the limit of wave action; the remainder, picked up again in the back rush of the water, is carried back directly down the slope, only to be moved further along the beach by the next wave.

A thorough analysis of wave and current action on coasts is found in Mr. G. K. Gilbert's interesting paper on "The Topographic Features of Lake Shores." This action may be summarized as follows: The agitation of the waves and the transporting power of the waves and undertow accomplish a sorting of the coast detritus. The finer portions are carried out to deep water; the remainder, clean sand and gravel, is left as shore drift, and the zone occupied by the shore drift in transit is the beach. It extends from beyond the line where storm waves break, to the shore line reached by the highest waves. The general profile is such that at each point the slope represents an equilibrium in transporting power between the breakers and the undertow. Where the undertow is relatively potent, the slope is gentle. Where the relative power of the breakers is greater, the slope is steeper. "The result is a sigmoid profile of gentle flexure, upwardly convex for a short space near its landward end, and concave beyond."* The outer bar of our coasts shows the first point of breaking of the storm waves.

Where the coast line turns abruptly landward, it cannot be followed immediately by the littoral current. Along the inner edge of this current, after passing the point of the shore line, velocity is reduced by the still water of the bay, the drift is deposited and a spit is formed. Where the littoral currents are of wind origin, they are intermittent. Then the materials of the spit may be spread by the currents to and from the bay, forming a bar like those off our southern coast entrances; where the spit is kept high enough to hold the transverse currents at its end, a hook is formed which, by a change of direction of the transverse current, may become a loop.

In all this littoral movement, the relative eroding and transporting powers of storms and calms are to each other as the similar powers of a stream during floods and low water. Movement on the coast is continuous, and the features of the coast show the resultant of all the action.

* Gilbert.

Stevenson and Harcourt give numerous examples of the power of waves in deep harbors and exposed situations. Examples of wave action on our own more protected coasts and in our shallow waters are not so numerous. In the report to the Chief of Engineers of 1890 on the Improvement of St. Augustine Harbor is the following:

"A wave may act on the jetty directly, by a blow, or a push, or a blow and a push combined; and, indirectly, by a pull, by compressing the air in the voids of the masonry, by upward pressure due to the difference of head produced on the two sides of the jetty, or by a combination of these actions. The direct action measured on the dynamometers had effects equal to pressures varying between 190 and 753 lbs. per square foot. This action took place when a wave broke directly on or in advance of the jetty; this also compressed the air in the voids of the jetty. * * * * Jets of water and sand were sometimes projected up from the cracks in the jetty to some height. The maximum height of any wave observed striking the work was 6 ft. * * * * Up to a height of about 2 ft. above mean low water, rip-rap weighing 40 to 50 lbs. was but little disturbed. Above this limit, to the height of 10 ft., the highest point observed, rip-rap varying in weight from 40 to 200 lbs. could not be held at any slope. An isolated piece of concrete weighing 350 lbs. and resting on its flat base 1.7 sq. ft. in area, with its center of gravity 7 ft. above mean low water, was moved several feet by breakers whose crests were about 7½ ft. above mean low water. These breakers measured 3½ ft. from hollow to crest. * * * * All that portion of a mound or wing, composed of rip-rap (varying in weight from 40 to 220 lbs.) tightly chinked with oyster shells, lying between 4 and 6 ft. above mean low water, no matter what side slopes the rip-rap was given, would be carried away in a single tide whenever breakers greater than 4 ft. in height struck it fairly. * * * * A block of concrete weighing 527 lbs. was elevated 1.3 ft. by the action of a single breaker. During the same tide it was moved 23 ft. inshore. A dynamometer within 8 ft. of its original position recorded a maximum pressure of 575 lbs. per square foot during this tide. A piece of concrete weighing 200 lbs. was lifted vertically to a higher level than that of the water surface by a wave which broke just in front of it. Another block of concrete weighing 1 600 lbs. was lifted from its bed vertically at least 14 ins., and then moved several yards."

Later, a concrete block 10 x 6 x 2½ ft. and weighing dry 21 000 lbs., lying about at the mean low water-line of the beach, was lifted vertically 3 ins., and there caught and held fast. The maximum wave height and dynamometer reading during that gale were 5.5 ft. and 633 lbs., respectively.

Another familiar effect of wave action was shown at Sandy Hook

where a line of rip-rap placed at the ordinary high water-line, composed of blocks weighing from 300 lbs. to 3 tons, was undermined and sunk into the sand from 4 to 6 ft. It may be stated generally, that where an obstruction is placed on a sand beach between high and low water, if it is too heavy to be moved, the resultant effect will be to smooth off the beach, either by sinking the object, or by building the beach over it.

Currents.—Having considered the mode of action of the sea by waves, there now remains the second form of attack—by currents. The eroding action of running water is too well known to require description, and the following principles only will be noted: First, the eroding power of water varies with the square of its velocity; second, feeble currents will transport material which they are powerless to lift from its bed without the help of some stirring action.

When a shoal of shifting material is crossed by tidal currents, as a rule the flow does not take place in any one channel to an equal extent in both directions. The slope of the bottom of the channel will show the direction of the maximum flow. Thus, flood channels have a gentle bottom slope up from the sea, with the least depth and steepest slopes at the inner ends. Channels in which ebb currents predominate have their least depth and steepest bottom slope at the sea ends.

There is another variety of sand movement which has been but little investigated, and the causes of which are somewhat obscure. It is well known that the surface of sand beaches and shoals varies in compactness to a marked degree from time to time. As generally stated, at times the sand is "alive," and the whole surface is soft and shifting. On the beach, between high and low water-lines, this may be a function of the dryness of the sand. At St. Augustine it was also found to vary with the time elapsed since the last deposit on the surface was made. After a gale, the new beach made during the gale would be very soft until it had been pounded down by the breakers of several tides. In shoals covered at all times by water, it is the general opinion, well supported by evidence, that the sand surface is alive during floods and more compact during ebbs. On the other hand, in investigating this subject at the mouth of St. Johns River in 1889, Mr. Bacon found that the maximum volume of sand actually in suspension close to the bottom of the bar channel during ebbs was three times the maximum flood volume.

A typical example of sand movement on the bottom (not in suspension) under the action of currents is found in the report of Mr. J. W. Sackett, United States Assistant Engineer, on his survey of the northwest entrance to the harbor of Key West. The sand there is coarse and light, and over 97% calcareous, being formed from disintegrated coral rock. A cubic foot of the sand, dry, settled by shaking, weighed 80 lbs. and contained 50% of voids. The grains varied in size from 0.005 to 0.08 ins. The water was very clear, and the bottom was plainly visible with the aid of a sponger's "water glass." The observations were made in depths varying from 7 to 17 ft. The coarser sand was always found where the velocities were the greater.

"We observed that the wave crests were at right angles to the direction of the currents. The wave length seemed to increase as the velocity of the current increased, until the maximum velocity was attained, when the wave length in feet was about two-thirds the current velocity in feet per second. It then remained about the same until the current changed its direction, when the waves would become obliterated. In the course of about half an hour after the current had assumed a definite direction, the waves were reformed correspondingly. The rate of advance seemed to be about one-fiftieth of the velocity of the current. The slope of the side toward the current was about 1 on 5; on the other side, it was about 10 on 4. At no time during these observations did the current velocity exceed 1.5 ft. per second." * * * * "On the sand bores * * * * the sand is quite coarse, and while passing over them in about 7 ft. of water, with a current setting across them to the south, probably less than 3 ft. per second, sand waves were seen as much as 7 ft. apart and 1 ft. high, and the sand seemed to be all in motion."* In rough weather this sand is so stirred up that the water over the shoals assumes a murky hue.

Coast Line, Plate I.—The portion of the coast under consideration extends from Cape Hatteras to Cape Florida. In 1857 Professor Bache drew attention to its bay-like form, and to the effect of this form on the tides within its limits. A line tangent to the two extremities has a bearing N. 21° E. Its length between tangent points is 700 miles. The maximum depth of the bight, measured at right angles to this line, is 200 miles, and is found in the neighborhood of Sapelo Sound, opposite the middle point of the tangent line. "The tidal wave setting into the southern bay rises as the bay contracts, and the heights of the tides along the shores increase as the places are more distant from the chord spanning the entrance." The bay-like formation is shown also

*Rep. Chf. of Engrs., 1890-II-1595.

in the slope of the bottom, which becomes flatter as the head of the bight is approached.

Seen from the sea, the shores of the southern bay present a monotony of scenery broken only by the openings into the many bays and inlets; everywhere is the sand beach backed by dunes over which a scant tree-growth shows. The highest land along the coast between Cape Florida and the highlands of Navesink is Mount Cornelia, at the entrance to St. Johns River, 60 feet high. The sand beach is continually in motion, with a resultant movement to the south. The source of the sand supply seems to be the New England coast. On the New Jersey coast the sand is coarse, with frequent beds of pebbles. To the south the pebbles disappear and the sand grows finer, until, at St. Augustine, 1 grain in weight of sand contains 2 050 particles, with an average diameter of .005 inches, and beds of broken shell are of frequent occurrence. South of Cape Canaveral tropical shells begin to appear in numbers on the beach. South of Cape Florida the silicious sand, which has been found all the way down the coast, begins to be mixed with beds of calcareous sand from disintegrated coral, and further south still the silicious sand has disappeared entirely, and calcareous sand alone is found.

The mean slope of the beach between the mean low water-line and the 3-fathom contour of the sea bottom is 1 on 45 off Hatteras, and decreases regularly to Sapelo Inlet where it has become 1 on 1 000. It then increases to Canaveral, where it is 1 on 55. The deeper contours show the same regular flattening in the bight. At each opening the regularity of the beach is broken and the contours, from 1 to 5 fathoms, are pushed out, to inclose an irregular fan-shaped area, or "bar," crossed by one or more shifting channels from the entrance, which generally incline more or less to the south.

The rivers emptying into the bays and inlets, or directly into the sea, have but slight slopes in their lower courses and are tidal streams for many miles from their mouths. The sediment brought down from their headwaters is deposited almost entirely in the interior basins. The amount reaching the coast is too small to be appreciable.

Whatever the problems arising in the interior improvement of the various harbors may be, the problem at the entrance is everywhere the same—how to control the moving sand. To do this, the nature and cause of the movement must be understood. To this end the action of the controlling forces, the sea and the winds, must be investigated.

Currents, Winds and Waves.—In his paper on the southern bay, Professor Bache continues:

"Beginning at Tybee entrance, Fort Pulaski, Savannah River, we have a good series of tidal stations to Hatteras, five in number. * * * * The mean co-tidal hour is 11 hours 52 minutes, and the angle which the co-tidal line makes with the meridian is 52° 9′, agreeing very nearly with the trend of the coast. * * * * The motion perpendicular to the direction of the co-tidal line is 24 miles in half an hour, agreeing very nearly with the velocity due to depths." * * * * "Group F is at the extreme southern portion of the series, where the tide wave is turned by the Bahama Banks and makes its way through the Straits of Florida. The three stations of this group are Cape Florida, Cape Canaveral and St. Johns entrance; of this, Cape Canaveral affords but a vague result. The co-tidal line makes an angle of 117° 12′ with the meridian, and the motion in half an hour is 29 miles" (see Plate I).

The positions of these co-tidal lines show an absence of any marked tidal currents along the coast. This might be expected, for, as stated by Prof. Henry Mitchell: "Tidal currents are rarely visible far from land, since they are called into activity by the delays and distortions of the tide wave consequent upon the resistances of shoals or confined and shallow channels." Corroborative proof of this absence of marked tidal currents is found in the statements of captains of coasting steamers to the effect that the direction of the currents depends on the direction of the wind; in the experience gained in the attempt to sink the caisson for the new Hatteras light, when currents were observed from some direction about all of the time, but shifting with the wind and totally independent of the tidal changes; and in the current observations off the Florida coast at and near the mouth of the St. Johns River.

As the tidal wave approaches the coast, when not influenced by the wind, the water rises nearly simultaneously all around the fan-shaped shoals off the entrances and pours into the interior tidal basins, gaining marked velocity and direction only after attaining the well-defined channels. Outside of these confined channels, the currents due to tidal action are too feeble to have any appreciable effect on the sand movement of the coast. This forms one of the many differences between the problems of our coasts and those of the narrow seas abroad.

The Gulf Stream is too far from the coast north of Cape Canaveral to have any known effect on the sand movement. Other currents are

at times observed close in shore with high velocities and generally northerly in direction, but their effect on the sand movement is slight. The great and marked changes on the coast are due to storm waves and currents, and the direction of the movement results from the direction of the wind. The resultant movement is in the direction given by the heaviest and most prolonged gales.

Winds.—At Hatteras and below, winds from northeast and east will produce a southerly, and from the southeast and south a northerly, movement of sand and currents along the coast. The reports of the Weather Bureau show that from 1886 to 1891, inclusive, observations made three times daily at Hatteras gave 1 333 observations of northeast and east winds and 1 045 of southeast and south winds, with the heaviest gales from the north. For Charleston, S. C., the numbers become 1 426 and 737, respectively. Further south the prevailing summer breezes are from the southeast. On the Florida peninsula, winds from the north and northeast give a southerly, and from the east and southeast a northerly, movement. At Jupiter Inlet the record from 1889 to 1991 gives 476 from north and northeast and 906 from the east and southeast. Nevertheless the sand movement along this coast, under the controlling influence of the northeast gales is also to the south, as shown by the reports of the engineers in charge of the works at Cumberland Sound, St. Johns River entrance, and St. Augustine.

Thus, in his project for the improvement of Cumberland Sound, Gen. Gillmore states—

"There is no evidence of a prevailing littoral current, although the Coast Survey chart shows that the flood produces a northern and the ebb tide a southern current along the coast. The shifting character of the bar is due to the combined and ever-varying action of winds, waves and tidal and storm currents. There are no tables of records, so far as I know, showing the duration and intensities of these agencies; their relative influence, therefore, can only be inferred from the observed magnitude of the results produced, and these point to the superior aggregate force of northeast winds, and the waves and currents produced by them."

Lieutenant Rees, reporting in 1892 on the survey of Brunswick outer bar, states that the resultant direction of the forces that move the sand and mold the shoals at that place is toward the south, and that the winds which produce a southerly movement of the sand are to those that produce a northerly movement as 29 is to 16.

This general sand movement along the coast must not be con-

founded with the local movement along the beach at each harbor entrance. As a general rule, unless the ebb currents are directed close along shore outside the entrance (as at St. Augustine, Fla.) there will be a local beach movement of sand toward the entrance at each opening in the coast line. This movement takes place generally during the rising tide, under the influence of the advancing waves and tidal currents of the entrance. In some instances, where the volume of flow through the entrance is great, there is a constant local littoral current of small velocity toward the entrance from both sides. During the flood inflow it is a part of the general movement of the water toward the interior tidal basin. During the ebb outflow it is from the eddy produced by the friction of the swift ebb current from the entrance on the still waters outside. This current undoubtedly has some influence in massing the sand on the two sides of the channel.

Under the forces acting, the sand of the open beach is always shifting, but the main features remain practically unchanged. At the openings in the coast line, the advancing sand continually tends to push the channels to the south. This southerly movement continues until the channel between the tidal basin and the sea becomes too long and the slope too slight to permit a velocity sufficient to equalize the difference of head at each tide. Then, frequently aided by a storm, the waters break a new and more direct channel, which, in turn, is pushed southward.

The general conditions prevailing on the portion of the coast under discussion may be summarized thus :

First.—The shores are low, fringed by a beach of light, shifting sand; the foreshore has a very gentle slope, giving comparative protection from wave action.

Second.—The heaviest and most prolonged gales are from the northeast, with occasional severe gales from the southeast.

Third.—The mean tidal range is from 1.5 to 7 ft., with two tides daily.

Fourth.—There are no continuous strong littoral currents, and no strong tidal currents excepting in the immediate vicinity of the openings on the coast line.

Fifth.—The coast storm drift of sand is large in volume with a resultant movement to the south.

Sixth.—This drift forms fan-shaped shoals across all openings on the coast line.

Seventh.—There is little or no fresh-water sediment brought to the coast line.

Eighth.—The channels across the shoals are generally shifting in character, and the navigable channels are maintained by the ebb outflow from the interior tidal basins, reinforced by the fresh-water discharge from the interior.

Improvement of Entrance to Cape Fear River.

A line drawn tangent to the coast of North and South Carolina at the head of the bights called Onslow Bay and Long Bay, respectively, will cut off a piece of land shaped like an isosceles triangle, with the equal sides somewhat concave (see Plate II). Cape Fear forms the vertex of the triangle, and Wilmington, N. C., lies a little beyond the base, about one-third of the distance along the base from the north point of tangency on Onslow Bay. The branches of the Cape Fear River unite in the vicinity of Wilmington. Just to the south of the imaginary base the river suddenly increases its width to one mile, and from that point to the sea it has the shape and characteristics of an estuary.

After passing Wilmington the direction of the river is nearly due south, and it holds this course until at Federal Point, 10 miles north from the extremity of Cape Fear, it is separated from the sea only by a narrow beach of $\frac{1}{2}$ mile width. There it turns slightly to the west, and, passing parallel to the coast, empties into the sea to the south of Cape Fear, 5 miles from its point. From Federal Point, for 6 miles, the barrier between the river and the sea is a narrow beach, 100 to 200 yds. wide, between which and the river channel are shoals from 1 to 2 miles broad. Then the barrier widens into a lozenge-shaped piece of marsh, known as Smith Island, with high ground on its southern face. Cape Fear forms the southern and sea point of the lozenge. Baldhead Point, its western angle, forms the eastern bank of the mouth of Cape Fear River. A higher point of sand between Federal Point and Smith Island is known as Zekes Island. Cape Fear is prolonged seaward for 17 miles by the Frying Pan Shoals, on which the depth varies from 7 to 16 ft. Appearances would indicate that the mouth of the river at some time had been near Federal Point, but that the coast sand movement had formed a bar and deflected it to the south, where it found a more sheltered mouth behind the obstruction which formed Smith Island and the Frying Pan Shoals. In its

present condition this strip of beach, with Cape Fear and the Shoals, form a natural jetty, which has enabled the river to maintain, unaided, a 14-ft. channel to the sea.

The distance from Wilmington to Baldhead Point is 27½ miles, and for this distance the area of the tidal basin formed by the Cape Fear River is 37 sq. miles, with a rise of tide of 4.5 ft. at the ocean and 2.5 at Wilmington. The mouth of the river is 1.25 miles wide. The estimated volume of flow through it is 160 000 cu. ft. per second for each tide. The average fresh-water discharge into the basin is 14 000 cu. ft. per second; and the influence of the tide is felt ordinarily for 30, and during very low stages of the upper river for 54, miles above Wilmington. The right bank of the estuary is low and marshy half way to the sea; elsewhere the banks are generally high and sandy. The channel between Wilmington and the sea, which had an available depth of 9 ft. in 1870, is being deepened to 18 ft. at mean low water by contraction and dredging. At two points in the river where the natural depth was 14 ft., many stumps of cypress and a few of pine trees were found firmly imbedded in the bottom, erect, and apparently in the position in which they grew.

The entrance to the Cape Fear River is obstructed by a bar occupying a fan-shaped area on both sides of the river mouth, 6 miles long on the coast line and 2 miles wide off the entrance. The main channel across this bar passes close to Smith Island, at Baldhead Point, directly seaward. It is known as Baldhead Channel, and is comparatively permanent in direction. A shoaler channel, known as the Western Channel, passes to the south, close around the point of Oak Island, which forms the west side of the entrance. Inside the mouth a well-defined channel, ¼ mile wide and with depths varying from 25 to 50 ft., extends as far as the Horseshoe Shoals, between Zekes and Smith Islands, a distance of 5 miles. The deep channel there is broken up, and a single well-defined channel is not found until after Federal Point is passed.

"Prior to 1761 the Cape Fear River was reported as allowing vessels of 14 ft. draft to pass over its main bar at low water, and to enter the river by the same route as they follow to-day. In 1761, however, during a violent equinoctial storm of four days' continuance, the wind and sea made a breach, reported at first as 18 ft. deep at high water, and later as not over 2.5 ft. deep at low water, and nearly ½ mile wide, through the sand banks to the Cape Fear River, about 8 miles above

its former bar entrance, at a place called Haulover (between Federal Point and Zekes Island). This breach, cutting off 6 miles of the river's length, gradually increased in importance, so as to form a new mouth for the river, deepening from 6 ft. at low water in 1797 to 10 ft. at low water in 1839, and received the name of 'New Inlet.' The effect of this new mouth upon the river was to diminish the depth of water upon the main bar entrance from 15 ft. in 1797 to 9 ft. in 1839." Up to 1839 "Baldhead Channel was the natural and main entrance to the river. From 1839 to 1872 both the rips (western channel) and New Inlet were the main entrances, and the use of Baldhead was discontinued. Since 1872, and the closure of the New Inlet, Baldhead has again become the main channel, and has been gradually regaining its former depth."*

In 1821 the State of North Carolina began the improvement of the river between Wilmington and the mouth, building some works of contraction, and dredging on the worst shoals. In 1829 the United States assumed charge of the work, and continued operations until 1841. During this period the channel depth below Wilmington was increased from 7.5 to 9.5 ft., the depth on the bar at the entrance. In 1852, with an appropriation of $140 000, the improvement of the mouth was started. A dike was built between Zekes and Smith Islands, to prevent a further widening of New Inlet, and a jetty 300 ft. long was placed at Baldhead Point for its protection. In 1857 a heavy gale wrecked the dike beyond repair with the funds available. The Baldhead Point jetty fulfilled its object until 1871, when it was flanked by the sea.

The next appropriation for this work was made in 1870. At this time the channel depth between Wilmington and the bar was 9 ft. The New Inlet was 4 000 ft. wide, had a least channel depth of 7.5 ft., and was traversed by tidal currents with velocities of 6 miles per hour. This least depth was found at its inner end, showing the preponderance of the flood-current action. Zekes Island had nearly disappeared, and between it and Smith Island was another opening 4 000 ft. wide in which the low-water depths varied from 0 to 20 ft. At the river mouth proper, the Baldhead Channel had decreased in depth to 7 ft., and the Western Channel had a depth of 9.5 ft. In the river channel, between Federal Point and Southport, for $2\frac{1}{4}$ miles at Horseshoe Shoals, the water-way was divided into several small channels, separated by bulkheads having on them depths of 9 ft. and less.

* Captain Bixby, Cape Fear River Improvement.

The total distance by river between Federal Point and the Baldhead Channel bar is 9 miles. The tidal changes at New Inlet occurred from one to two and a half hours before the influence of the change at Baldhead Channel bar could be transmitted through the river channel to the same point. In 158 tides observed in 1880, the average greatest differences in height on the two sides of the New Inlet dam were 1.14 ft. during floods, and 1.53 ft. during ebbs, the greatest being 2.5 ft. for floods and 3.4 ft. for ebbs. The water on the sea side was highest during floods and lowest during ebbs. There resulted, before the dam was built, an interchange of water between the two entrances at each change of tide, with corresponding ill effects in the river channel, as shown by Horseshoe Shoals below Federal Point. The material of the bottom and sides of New Inlet and of the beach was sand. Back of the beach, north of Smith Island, was found marsh mud, with occasional oyster bars. The shoals were composed of a mixture of mud and sand.

It was decided to deepen the channel over the entrance bar by deflecting all of the flow through the one mouth by closing the openings through the beach, assisting the natural scour by dredging ; also, to dredge a channel through Horseshoe Shoals. The first step was to build up Zekes Island and to close the opening between it and the beach extending north from Smith Island. This was successfully accomplished in 1873. The new dike then formed the south side of New Inlet. During the same year the beaches were built up several feet by sand catches and plantations of beach grass.

The dike across New Inlet was then started. It crossed the inner end of New Inlet and joined the north end of Zekes Island dike. After much difficulty, on account of the rapid currents and the unstable material of the bottom, this was finished in 1881, completely closing New Inlet. The effects of the work were manifest at once at the river mouth. The currents there were increased, and the flow became more concentrated. Baldhead Channel deepened to 10 ft. in 1874, and to 14 ft. in 1881, while the Western Channel shoaled to 9 ft. in 1874, and to 6½ ft. in 1881. The beach began to form, immediately, across the mouth of New Inlet, until in 1880 the visible accretion in that neighborhood was over 1 500 000 cu. yds.

As soon as New Inlet was completely closed, the river and sea sought to flank it by cutting through the beach north of Smith Island.

An attempt was made to close this "swash" by light pilework, but the tidal currents were too strong and the exposure too great. As these swashes continued to increase in width and depth, a new dike was determined on to connect Zekes Island with the Smith Island marsh, and thus to prevent effectually an injurious deepening of the swashes. For its better protection it was placed ¾ mile back from the beach, near the inner edge of the shoals which there form the river bank. This was finished in 1888; since that date there has been a continual increase of the height and width of the outside beach. After 1870 Baldhead Point began to wear away rapidly. At the same time a hook was formed, leading inward from the point, which held the mouth at its existing width, neutralizing the effect of the erosion. In 1886 a large accretion began to form to the southeast of the point. In 1889 this accretion had reached the point, and it still continues.

In 1874 a suitable hydraulic dredge was bought for work on the bar. She worked there, weather permitting, during 1874–75, 1878–82, and from 1887–92, and removed in all 395 000 cu. yds. of sand from the bar channel and 155 000 cu. yds. from the channel through Horseshoe Shoals. She also worked, from time to time, during four more years, during which no record was kept. Since 1870 dredging has been carried on by contract, as well, in the nine shoals between Wilmington and the mouth, and under the demands of the increasing commerce the protected low-water channel depths have been increased from 12 ft. in 1874 to 16 ft. in 1881, and 18 ft. in 1892. The total amount of material removed up to June 30th, 1892, was 4 778 000 cu. yds. The total cost of the improvement from 1870–1892 has been $2 271 300. The results have been the formation of a channel having least depths at mean low water of 17 ft. at outer bar in Baldhead Channel, and of 16 ft. through Horseshoe Shoals and thence to Wilmington, excepting for 300 ft. at Lilliput Shoals, near Wilmington, where the depth is 15 ft.; while the total commerce of the port has increased from a valuation of $13 500 000 in 1870 to a valuation in 1891 of $23 093 120.

The channels, as formed, will need dredging from time to time, and near Horseshoe Shoals will require the assistance of deflecting works; but the main work, the closing of the false river mouth, seems stable, and by the growth of the outside beach, gains strength year by year. The tidal ranges, at Wilmington and Southport, have remained unchanged throughout the improvement.

Methods and Plant. Zekes Island Dike, 1870–73.—This dike was built of timber cribs, filled with stone, and floored and covered with plank. This method of construction, similar to that in use on the Great Lakes, was adopted to save stone, timber being cheap and stone dear. The work was started from the Smith Island Beach, and, as it progressed, much difficulty was experienced in placing the cribs on account of the high velocities in the narrowing water-way, which induced so much scour that two of the cribs were sunk in water 30 ft. deep.

"From the very commencement of the work at Smith Island, a sand spit, somewhat above high water-mark, followed along on the outer or sea side of the work; its extreme point, however, always keeping a little behind the advanced superstructure. Nor would this sand spit join the work at any point, but followed along in a direction generally parallel to the work, and at a distance from it varying from 40 to 200 ft. This left a water-way along the work in which the tide rose and fell with the tide of the Inlet. It was partly supplied, however, by water, which, at certain points (particularly at the deep holes), leaked through the crib-work. To avert any disaster which might result from this, and to encourage the accumulation of sand on the outer side to protect the timber from worms, several useless and worn-out flats were sunk at the narrow points of this water-way, connecting the work with the sand spit. About 30 000 sand bags were also filled and deposited along both sides of the work. The result was that several ponds were formed along the outer side, which began rapidly to fill up with sand. As the superstructure approached completion, the accumulation of sand became very rapid, not only in the ponds, but along the entire work. Numerous shoals—far beyond the sand spit—also began to show themselves at low water."*

This dike soon was covered completely by sand, and was never seriously damaged by the gales. It was 4 403 ft. long, and cost $60 per running foot. It was finished in 1873.

New Inlet Dike, 1874–81.—To provide a good landing, and to make a shelter for flats and boats used in the work, a crib-work pier, 500 ft. long, was built from Federal Point into New Inlet.

"As the work progressed, a very serious deepening occurred in advance of the line of cribs. By the time 200 lin. ft. had been placed in position, cribs 12 ft. in depth were required where originally there were only 6 ft. of water; and when, in November following, the last crib (completing the 500 ft.) was placed in position, it was sunk in 19 ft. of water, the original depth having been only 6 ft. Many of the cribs settled rapidly after having been put in position, and it was only by great

* Captain Phillips, Rep. of Chf. of Engrs., 1876–I–325–326.

exertions that the cribs could be built upon fast enough to keep them above low water-mark."* The use of cribs was then abandoned.

In 1875 the final closure of New Inlet was begun by laying across the remainder of the Inlet an apron of log mattresses (with the logs at right angles to the axis of the jetty) covered with a layer of brush and loaded with stone. The total length was 4 300 ft., and the width of mattresses varied from 40 to 70 ft. according to the depth, being designed for a top width of rip-rap dike of 16 ft. at ordinary low water, with a slope of 1 on 2 toward the sea, and of 1 on 1 toward the river. The scour in advance of this apron was about 3 ft., and before the dike was built upon it, there was no settlement after the mattresses were placed in position. At the close of the fiscal year 1878, the apron had been raised to the low water-mark, and this partial stoppage developed a difference of head on the two sides which, toward the close of the ebb, became at times as great as 2 ft. There was also a heavy flow across the top of the dike. The inherent weakness of the log mattress apron quickly showed itself. Under the pressure produced by the head, in all the shoaler portions of the work, the water found its way between and under the logs of the mattresses, and gradually settled the foundations, so that there was no portion of the dam (excepting short lengths at the shores) where the base was less than 12 ft. below mean low water. No settlement was observed where the original depth exceeded 14 ft. at mean low water.† The scour along the edges of the foundations, due to flow over the dike, was generally from 8 to 12 ft. Work was continued, as funds became available, by building up the crest with rip-rap until the limit of subsidence had been reached. It was then capped with heavy stone.

In 1881 the dike was practically completed. Its crest is 1 ft. above high water of ordinary spring tides. Above the low water-line it has a capping of undressed granite blocks, weighing from ½ to 4 tons, laid by hand to a smooth face, and having a slope of 1 on 2 on the sea face and a more gentle slope to the rear. The bulk of the dike is composed of one man stone, which took a slope of about 1 on 2 on the sea side and of 1 on 1½ on the land side. The whole dam is 4 752 ft. long, contains about 182 821 cu. yds. of material, and cost complete about $2.75 per cubic yard, or $105 per linear foot.

* Captain Phillips, Rep. Chf. of Engrs., 1876–I–325, 326.

† Mr. Bacon, Rep. Chf. of Engrs., 1878–I–477.

Dike Across Shoals, 1883–88.—The foundation consisted of a brush mattress apron, part in sections and part continuous, in 5 to 12 ft. of water. This mattress was broad enough to extend beyond the side slopes of the dike, and thus to act as an apron for overflow. It consisted of three layers of brush, of which the lowest was transverse to the axis of the jetty, the next longitudinal, and the third transverse. These were compressed and held by fascine ropes, or binders, 5 to 8 ins. in diameter, strongly bound with spun yarn. The binders were parallel to the axis of the jetty, and were spaced 3½ to 4 ft. apart, in sets of two, one above and one beneath the mattress. The brush was compressed between the binders by a lever to the full strength of the 9 to 18 thread ratlin which tied the upper and lower binders together. The average thickness of the mattresses after compression was 9 ins. They are described as strong and pliable. A portion of the foundation was made of separate mattresses, constructed on a tilting table, 90 x 30 ft., and towed to the site of the work and sunk. Five thousand two hundred feet of the foundation was made of continuous mattress work in two parts, 3 100 and 2 100 ft. long, on a scow 80 x 28 ft., provided with an inclined table 60 x 36 ft. A section having been launched, its binders were spliced to binders on the scow, another section was made, and the scow run from beneath on the line of the axis as before. The sinking of the mattress by stone followed a short distance behind the scow. In the small mattresses made on the tilting table, it was found that by practice an average of 25 ft. in length of fascine binders was made each hour by one man. After the fascines were ready and the binders spliced, the mattresses were made and fully bound at the rate of 7½ sq. yds. for each hour's labor. The cost of labor on mattresses and binders was 3½ cents per square yard of mattress. The cost of labor on the continuous mattresses made on the scow was about 5 cents per square yard. The cost of each style in place was about the same. The cost of the mattresses in place, including materials and plant, was 66.2 cents per square yard, or, allowing 46% for compression, about $2.65 per cubic yard. The cost of the stone in place, including handling, superintendence, etc., was about $2.30 per cubic yard, assuming 1.12 cu. yds. to the gross ton (the stone used for sinking the mattresses was a very light shell stone).

The dike was finished in 1888. The total amount of stone used in construction was 76 000 cu. yds. Its crest is 6 ft. wide and is at the

level of high water of ordinary spring tides. The side slopes are 1 on 1½. The crest and slopes to low water are capped with heavy stone, hand laid to a smooth face, with an average thickness of 9 to 12 ins. The cost of the labor of placing, including wages of foreman, but not superintendence, was 28.5 cents per superficial yard. The average subsidence of the dam due to settling in the mud, compression of mattresses and consolidation of rip-rap was about 2 ft.

Hydraulic Dredge "Woodbury."—This boat was bought and fitted as a dredge in 1874 and repaired in 1880. She is a propeller of 145 tons burden, and is provided with a 9-in. centrifugal pump, driven by a double oscillating engine, with 10-in. cylinders, and has two suction pipes of boiler iron with an internal diameter of 6¾ ins. Her average day's work was 515 cu. yds. Her bin capacity was 45 cu. yds., and the bins were frequently filled in 25 minutes. She could dredge in 6 to 14 ft. of water. She proved exceptionally efficient for ocean-bar work, where wave action is heavy, and was used in Baldhead Channel. When driven from there by storms, she dredged in the Horseshoe Shoals channels. The cost of her dredging, including repairs and an allowance for deterioration, varied between 11.75 and 14.8 cents per cubic yard. The contract price for similar dredging in the smooth water of the river during the period under discussion varied from 12 to 16.7 cents per cubic yard.

Remarks.—The history of this work may be summarized as follows: Prior to 1761 the river had but one entrance, the channel was straight and permanent, with a depth of 14 ft. Its direction was that taken by the ebb currents from the river. During a heavy gale accompanied by an exceptional tide, the sea swept across the unprotected sand barrier 9 miles above the bar, and the times of the change of tides on the two sides of the barrier being an hour apart, the difference of head developed tidal currents which scoured out the sand and opened a new mouth. The power of the ebb currents being divided, the original channel shoaled, and three channels were developed of which two, the New Inlet and the Western, had the characteristics of flood channels, all with less available depth. The false mouth was closed, and the single channel with its greater depth was re-established.

From the history of the first dike is seen the inadvisability of closing a channel having rapid currents over an unstable bottom by a dike built from one side, to full height, with large unyielding

elements (cribs), causing heavy scour in advance, under and between the elementary parts. The rapid advance of the sand spit along with and separated from the dike, and its extension to the dike by the use of spurs, and the tightening of the dike with sand bags, are characteristic.

In the New Inlet dike is seen the advantage of the continuous low apron laid in advance, an advantage which is partly lost by the stiffness and permeability of the log mattress, which, unless very wide, and on a bottom perfectly level on the line of the logs, affords, under pressure, a water-way under and between each of its elements, with consequent scour and increase of depth. (This same action will be found later in the history of the St. Johns improvement.) There is also seen the scour produced by the overflow before the dike had reached its full height, and the final closure of the water-way by simple rip-rap, which, following up the scour, soon reached the limit of settlement. A more detailed history would show also that it was impossible to hold light rock in the dike above the level of mean low water under the wave action of even so sheltered a location without a capping of heavy blocks, laid with smooth and gentle slopes, and with the joints carefully chinked.

In the third dike is found a better form of mattress, more pliable, and with no continuous water-ways, and an apron at the side to protect from scour. Of this foundation Mr. Bacon, the assistant engineer in local charge, says:

"Notwithstanding the pliability of the mattresses, and the fact that the bottom fascine binders are longitudinal with the dam, the water found its way under the mattresses and caused a subsidence in many places where it could be definitely observed at low water. * * * * The experience of many years has convinced me that the foundation placed on sand or mud most secure from undermining by water is of small stone rip-rip. In a soft foundation of comparative stiffness, rip-rap will settle more or less and finally secure the characteristics of an unified platform, and will support the weight required of it with perfect stability. In a formation of sand, the limit of subsidence is soon reached, and the water ceases to pass under the stones. Whenever the mattresses are not covered with sand or mud and are below half tide, they are thoroughly eaten by the teredo worms. All kinds and sizes of wood are thoroughly perforated, down to $\frac{3}{16}$ in. in diameter." *

The enormous extent of the coast sand movement is seen from the

* Rep. Chf. of Engrs., 1885–II–1092.

fill in the beach outside New Inlet, and the tendency to form a continuous coast line from the rapid closure of the inlets when the currents through them were stopped.

This successful work was in charge of Colonel W. P. Craighill from 1870 until 1884, of Captain W. H. Bixby from 1884 until 1891, and since that date, of Major W. S. Stanton. The assistants in local charge were Captain C. B. Philips, 1872 until 1876; Mr. Henry Bacon, 1876 until his death in 1891; and, since that date, of Mr. E. D. Thompson.

Charleston Harbor Entrance.

The City of Charleston lies on the point of land formed by the junction of the Cooper and Ashley Rivers. The lower reaches of these rivers, with the irregular water-way between Charleston and the opening in the coast line between Sullivans and Morris Islands, form the harbor, with a tidal basin of more than 15 sq. miles area. There are two tides daily with a mean range of 5.1 ft. An extreme range of 10.3 ft. has been observed. The mean duration of rise is 6 hours 15 minutes, and of fall 6 hours 9 minutes. The average discharge during ebbs through the throat of the harbor, $1\frac{5}{8}$ miles wide, between Sullivans and Morris Islands, has been estimated to be 3 655 000 000 cu. ft., of which about 76 000 000 cu. ft. is supplied by land drainage. The capacity and safety of the harbor is shown by the map (Plate III).

The entrance, or throat, of the harbor lies at the head of a shallow re-entering angle of the coast. The coast line, rectified between a point on Long Island 8 miles northeast of the entrance, and the extremity of Morris Island, $3\frac{1}{2}$ miles to the south, would be $2\frac{1}{2}$ miles off Fort Moultrie at the entrance, and $\frac{3}{8}$ mile to 3 miles inside the 18-ft. contour of the fore shore. The shoals known as the Charleston Bar, formed by the influence of the harbor on the coast drift, begin at a point about 1 mile northeast of the entrance, off Sullivans Island, and separated from it by Beach Channel, $\frac{1}{4}$ mile wide, and extend from there down the coast for 7 miles. The general depth on the crest of the shoals varies from 3 to 9 ft., excepting in the channels. The 18-ft. contour of the outer slope is about 1 mile seaward from this crest, and the average width of the bar between the 18-ft. contours is $1\frac{3}{4}$ miles. Charts extending back to 1780 show that the bar has varied comparatively but little in extent, direction, or in distance from the mouth of the harbor. The main central body of the bar is 5 miles long.

The surface of the bar shows materials closely resembling those found on the seashore in that section of the country, being shells, fragments of shells and silicious sand. Borings in the northern end of the bar showed some layers or lumps of mud, or of sand and shells mixed with mud. "So far as we can now ascertain, there appear never to have been less than four nor more than six ship channels across the bar at any one time. The greatest depth of water has sometimes been found in one channel and sometimes in another, being rarely less than 12 ft. or more than 13½ ft. at mean low tide. These channels, whether four or more, have always existed in two groups or clusters, one in the northern and one in the southern curved portions of the bar, and there has always been a deep and broad anchorage inside the straight reach of the bar abreast of Morris Island. * * * * At the extremities of this outer harbor or basin, several miles apart, are found the two groups of channels already mentioned, the most northerly group being directly in front of the gorge of the harbor."

"The bar is essentially a drift and wave bar * * * * The peculiar location of the bar, largely to the southward of the gorge of the harbor, and the conditions under which a very large proportion of the ebb flow is diverted from its most direct path and forced to skirt the main coast for several miles before it can find a passage to the sea, indicates the controlling power of these (northeast) storms."*

All the channels across the bar have the characteristics of ebb channels excepting Beach Channel, now closed, and a shallow channel close along the Morris Island shore. The reports of the chief signal officer quoted earlier show the predominance of the northeast gales. The mud lumps on the bar are easily accounted for by the erosion of the beach to and through the underlying marsh mud. Observations made in 1878 showed ebb velocities of 1½ to 1¾ miles per hour in the north channel in depths of 8½ to 9 ft., and in 22 ft. of water on the outer slope of the bar of 1 mile per hour at the surface and ½ mile per hour at the bottom. "Other observations made at different points of the harbor simultaneously showed that the flood tide made its appearance first in the Beach Channel and afterward in each of the channels to the south of it in succession, the last of the ebb passing through what is called the Main Ship Channel to the Pumpkin Hill and South channels."†

The first appropriation by the United States for the improvement of the harbor was made in 1852. It was applied to deepening Beach

* Rep. Chf. of Engrs., 1873-I-555.

† Rep. Chf. of Engrs., 1878-I-546.

Channel by dredging, but without substantial results. A short jetty was also built near Fort Moultrie on Sullivans Island, to protect the beach from erosion. Other appropriations were made between 1871 and 1876. These were used in removing a portion of the Bowman Jetty on Sullivans Island, for the purpose of straightening Beach Channel, in dredging in Beach Channel and in the removal of wrecks. In 1874 and 1875 the authorities of the City of Charleston attempted to deepen the Pumpkin Hill Channel by dredging. None of the dredging operations afforded permanent relief.

In 1878 a project was adopted for deepening the channel over the bar to 21 ft. at mean low water by means of jetties, in accordance with the plans of the late General Gillmore. It was proposed to construct two jetties, one springing from Morris Island and the other from Sullivans Island, curving toward each other in such a manner that their outer ends on the crest of the bar should be $\frac{1}{2}$ to $\frac{5}{8}$ of a mile apart. The outer ends of the jetties were to rest on the shoals to the north and south of the middle channel of the north group of three channels, with the line of the proposed jetty channel nearly in the prolongation of the axis of deep-water flow through the gorge of the harbor between Cummings Point and Fort Moultrie. The jetties were to be submerged, especially at their inner ends, but the total length and height were to be regulated by the results obtained.

Work on the north jetty was begun in December, 1878. A foundation course of log mattresses, varying in width from 40 to 118 ft., ballasted with stone, was laid to the crest of the bar, a distance of 14 330 ft., with a total height of from $2\frac{1}{2}$ to 4 ft. Beginning 5 300 ft. from the shore end, for 5 800 ft. seaward, there is a second course of mattresses and stone. The width of the mattresses varies from 55 to 90 ft., according to the depth. Up to June 30th, 1892, 175 155 sq. yds. of mattresses and 159 369 cu. yds. of stone (at 2 600 lbs. to the cubic yard) had been used in the construction of the jetty.

The south jetty was started in 1880. In 1887 the foundation course of stone-ballasted mattresses had reached a point 16 440 ft. from the shore end on Morris Island. The width of the foundation varies from 40 to 130 ft. In the deep water at and near the crossing of the existing main ship channel, the width of the bottom course was increased for 4 256 ft. by a mattress apron to from 135 to 206 ft. A second course of mattresses was laid in the deepest portions for 10 586 ft., and a

third course for 1 206 ft. For a portion of the distance short spurs were made by having each third mattress of the foundation course longer than the other two. Beyond the main ship channel fifteen sets of spurs, 100 ft. long and 50 ft. wide, were laid. Up to June 30th, 1892, 306 585 sq. yds. of mattresses and 212 301 cu. yds. of rock (at 2 600 lbs. per cubic yard) had been used in the jetty.

The width between the sea ends of the jetties, center to center, is now 2 900 ft. The heights and lengths on June 30th, 1892, can be seen on the profiles shown on Plate IV. Above the mattress work the stone is ridged along the jetty axis with a crest about 10 ft. wide. Under wave action the crest is lowered, and the stone assumes stable side slopes. When desirable, the crest is raised with more stone. Work on the jetties continues. Until the sailing gap, which has been left at the point where the main ship channel crosses the south jetty, has been more nearly filled, the extent to which the tidal flow must be restricted by the jetties in order to form and maintain the desired depth of 21 ft. at mean low water in the jetty channel is more or less conjectural. Too many conditions must be considered to permit this to be calculated. This gap cannot be closed until the jetty channel has become the main ship channel, and the usefulness of the old ship channel has ceased.

The cost of the mattresses in place was from 49 to 72 cents per square yard; of the ballast stone in place, from $3.09 to $3.60 per cubic yard; of the one man stone in the superstructure, $1.90 per short ton ($2.47 per cubic yard); and of the heavy stone, in ½ to 5-ton blocks, from $1.90 to $2.15 per short ton ($2.47 to $2.80 per cubic yard), not counting cost of inspection and superintendence. The total cost of the work, including the protection of Morris and Sullivans Islands and dredging, from 1878 to June 30th, 1892, is about $2 190 000. The cost of the jetties to the same date has been $70.46 per lineal foot.

In 1884 and 1885, 85 549 cu. yds., and from 1890 to 1892, 205 421 cu. yds., of material were removed from the jetty channel by dredging. The cost of the dredging by contract was in 1885 30 cents per cubic yard, and in 1890 and 1891 17¼ cents per cubic yard. Dredging carried on with United States plant cost in 1892 11½ cents per cubic yard.

The results of the work on the jetty channel have been (1) a general movement of the crest of the bar there seaward, between 1882 and 1892, of 3 600 ft. in the north third, and of 5 600 ft.

on the middle third, between the jetties; (2) an increase of least depth of $1\frac{1}{2}$ ft. in the first area, or $3\frac{1}{2}$ in the second, and of $\frac{3}{4}$ ft. in the south third; (3) an increase of the outer slope of the bar from 1 on 300 to 1 on 200 in the first area, and from 1 on 200 to 1 on 150 in the middle area; and (4) a general deepening of the entire area between the jetties. The advance of the outer slope of the bar, as shown by the 18-ft. contour, was about 400 ft.

More recent surveys show a least mean low-water depth of 15 ft. (in February, 1893) on the sailing range; a further increase of the general depth between the jetties; and a further movement seaward of the crest of the bar between the jetties. "The water between the jetties at the strength of the ebb tide is about 7 or 8 ins. higher than it is on the outside at the same distance from shore. This is the maximum difference, and is found, say, about 1 000 ft. outside of the present inner end of the high-water portion of the south jetty."* Recent current measurements show a corresponding increase in the strength of the ebb currents in the jetty channel.

Materials and Methods.—The last advertisement for proposals, calling for bids to furnish mattress work, stone and dredging, describes the mattresses to be used as follows :

"Rafts of round logs will be prepared. The logs must not be less than 12 ins. average diameter, and no log shall be less than 9 ins. in diameter at the small end. They must be placed in close contact, side by side, and firmly held by transverse pole binders, spiked to them with spikes not less than 15 ins. long. A layer of live wood brush, 1 ft. thick when closely packed, will be placed upon the logs and secured by poles lashed to the binders of the raft. The binders will be small logs or poles not less than 6 ins. in diameter at the small end. They will be placed not more than 8 ft. apart, and those on the outside will be close to the end of the logs."

The mattresses are to be 100 ft. wide. These, when used, are to be covered with 3 ft. of stone in pieces not less than 10 lbs., nor more than 250 lbs., in weight. They will be used, should a further extension of the jetty be decided upon. On these will be piled stone, in pieces from 1 to 7 tons in weight, along the axis of the jetty to the level of high water, with crest from 5 to 10 ft. wide, and such side slopes as the stone will take.

All stone is required to be hard and compact, and, where exposed to wave action, it must be hard and heavy granite. It is to be paid for in tons of 2 000 lbs., as determined by railroad weight, or by the displacement of lighters, provided with a 3-in. well within 12 ft. of each

* Captain Abbot, letter of March 14th, 1893.

end, to measure the draft, as will be described later. The displacement of the lighters under the various loads will be determined by piling on known weights. The prices for stone under these specifications are $3.20 per ton for shore work, and from $2.25 to $2.35 for the remainder, according to the location of the work; for mattresses, the price bid is $1.25 per square yard, and for dredging, 28 cents per cubic yard. The mattresses, as described above, are practically the same as have been used throughout the work.

Since 1889 a large proportion of the stone used in the work has been taken from the Government quarry at Edgefield, 144 miles from Charleston. It is brought by rail to Charleston and lightered to the jetties. The work was done by hired labor until October, 1893; since that date, entirely by contract. Excepting the railroad equipment, about one-third of the plant used is the property of the United States, which is now hired by the contractor. The rock is a heavy compact granite, and is taken out in blocks weighing from 20 lbs. to 7 tons, as much as possible in the large sizes. It is placed in the jetty by the aid of a derrick-scow, which carries a Lidgerwood hoisting engine, capable of lifting 8 000 lbs. on a running line, and operating a turn-table derrick of 10 tons capacity. No special difficulty was found in handling the rock in the swells prevailing, excepting that the elasticity of the line was insufficient to enable the cog-gearing of the turn-table as first used to withstand the shocks incident to lifting the heavy weights in a seaway. It had to be replaced by another device. The saving to the United States in 1892 by the use of its own quarry and plant amounted to between 40 and 50 cents a ton, without any allowance for cost and deterioration of plant. At present the work is all done by contract, pursuant to the provisions of the River and Harbor Act of July, 1892, the Government plant being rented to the contractor for $3 375 per month.

Dredge.—In 1891 a hydraulic dredge, suitable for work on the bar, was built by the United States. The dredge is 122.5 ft. long, 30 ft. beam, and has 12 ft. depth of hold. She is furnished with a steeple, compound, Sullivan, propelling engine, with cylinders 17 and 32 ins. in diameter, and 22-in. stroke. She has one propeller, 7 ft. in diameter, and on her trial trip, without a load, had an average speed of 10 miles per hour. Her pumping machinery is of the B. C. Howell pattern, and consists of a 230 H. P. compound engine, coupled direct by a shaft to a centrifugal pump with a 14½-in. suction, and a 15-in. discharge pipe. Her maximum bin capacity is about 270 cu. yds. Her crew is 16 men.

Experience had shown that on a sand and drift bar, in a seaway, such as is found between the jetties, dredging can be carried on economically only by a powerful, self-propelling, hydraulic, hopper dredge, having sufficient speed and bin capacity.

It is interesting to note that hydraulic dredging with a centrifugal pump was invented at Charleston in 1855 by Mr. Lebby. The late General Cullum was at that time the engineer in charge of the harbor work. He was much impressed by the capabilities of the method, and with his encouragement a powerful propeller was fitted with a bin and a pump 6 ft. in diameter, having a 19-in. suction. She was used in the Sullivans Island channel in 1857 with great success, the average day's work being 328 cu. yds. and the maximum 1 005 cu. yds. Although manifestly the method most suitable for dredging in a rough seaway, it seems to have fallen into disuse during the Civil War. It was revived in 1871, when the steamer *Henry Burden* was fitted for hydraulic dredging upon plans devised by Captain (now Major) William Ludlow, Corps of Engineers, under the orders of the late General Gillmore, substantially in the manner still in use for hydraulic dredging from a steamer under headway. A full description of her, as she was fitted in 1875, is to be found in the Annual Report of the Chief of Engineers for 1875. She did efficient service in Charleston and several of the other South Atlantic Coast harbors.

Remarks.—General Gillmore's project for the improvement of Charleston Harbor has been criticized widely, both favorably and unfavorably, by members of the engineering profession. A cause for a portion of the unfavorable criticism may be found in the apparent delay in the attainment of marked results. This delay is, however, accounted for fully when the scope of the project is understood and considered along with the meager and intermittent supply of money for carrying it into execution. The estimated cost of the completed work, as revised by Captain Abbot, the engineer in charge in 1889, is $4 380 000 if the jetties are built to mean low water only, and $5 300 000 if brought throughout to 3 ft. above mean low water. Up to June 30th, 1892, the appropriations averaged $157 000 per annum, made in nine appropriations, an annual allowance of about 3½% of the total cost.

The reasons which guided General Gillmore in the formation of the project are to be found in Part I, Report of the Chief of Engineers, for 1878. His recommendation to keep the inner ends of the jetties

submerged is for the two-fold purpose of admitting the flood tide more freely and of attempting to prevent any considerable seaward movement of the main body of the bar. The growth seaward of the shore on the north side of a high north jetty at Charleston was to be anticipated from the known sand movement of the coast and from the observed effects at other harbors. It was General Gillmore's belief that with the inner end of the north jetty low, the moving sand would cross the jetty, be carried to sea by the strong ebb current from the harbor, and then be moved to the south, after passing the ends of the jetties, by the same storm movement which brought it in. Up to the present time absence of growth of the shoal north of the north jetty, and the continuous, though slow, deepening of the jetty channel, apparently show the correctness of this hypothesis. It remains to be seen whether the ebb currents can be sufficiently controlled by the submerged jetties to produce head enough to create the velocities necessary for scouring out the deeper channel.

Though progress has not been rapid, the final deepening of the jetty channel cannot be doubted. Should a modification of the jetty heights be necessary, it can be made easily. The present work of ridging the stone above low-water level is only temporary in character, and a lowering under wave action is expected. The crest can be raised and made permanent later, or left low, as may prove most expedient. In the meantime there is no increase in cost, and with each month valuable information is gained from the observed effects.

The log mattresses, as used in Charleston Harbor, have proved satisfactory to the engineer in charge for foundation work. For a rough site, he condemns them.

"Where ridged stone has been used in the work done under previous appropriations, it is impracticable to use mattresses (log) unless the ridge be first leveled off. * * * * Mattresses which sunk in perfectly good shape on the rough stone piles near the former Drunken Dick Gap, broke to pieces as they received the additional loading of stone, and some of the logs stood up 10 or 15 ft. above the general level. It was found to be very hard to get stone to stay on them at all, the mattress breaking in the middle, forming a sort of sloping roof to the work beneath, and the rip-rap sliding off into deep water on either side."*

The reported settlement in the low jetties was generally from 1 to 2 ft., excepting in Beach Channel where it was $3\frac{1}{2}$ ft. No settlement has been reported since the jetties crossed the natural channels. When

* Captain Abbot, Rep. Chf. of Engrs., 1889-II-1154.

the north jetty was being extended in 1879, a shoal, known as Drunken Dick Shoal, was found having on it too little water to float the mattresses. A gap was left, and the jetty started beyond the shoal. The shoal up to that time had varied but little in position. It was thought that, should it remain permanent, it would act as part of the jetty. If not, the gap could be filled. By 1881 the shoal had scoured in places to a depth of 11 ft., and the jetty was extended across its site. This illustrates a fact not always appreciated by engineers not familiar with work in such localities—that shoals of any erodible material are permanent only so long as the surrounding conditions remain unchanged. It is not safe to depend on them for a part of a system in connection with new constructions. No matter how permanent in position and extent they may have seemed, the sand bars along our southern coast are really in a state of unstable equilibrium, and are subject to radical change with a change of conditions.

The Charleston jettywork was started under General Gillmore, and he remained in charge until his death in 1888. Since that date Captain F. V. Abbot has been in charge. The assistant engineers have been Captain J. C. Post, Captain B. D. Greene, Lieutenant T. N. Bailey and Lieutenant F. V. Abbot, of the Corps of Engineers, and under Captain Abbot, Mr. James P. Allen, C. E.

Savannah Harbor.

The harbor of Savannah is formed by the lower Savannah River, an estuary opening into the sea at Tybee Roads, which above Savannah receives the discharge from the upper river. The distances of points on the estuary from the Whistling Buoy off the entrance, together with the tidal regimen of the estuary, are given in the following table:

	Distances, miles.	Corrected establishment.	Mean luni-tidal interval of low water.	Mean duration of—		Height above m. l. water at Fort Pulaski.		Change of current after—	
				Fall.	Rise.	H. W.	L. W.	H. W.	L. W.
Whistling Buoy	0	h. m.	h. m.	h. m.	h. m.	ft.	ft.	h. m	h. m.
Tybee Island	7	7 15½	13 26	6 10½	6 14½	6.9	0.02	....	....
Fort Pulaski	9.5	7 15½	13 54	6 38½	5 46¼	6.97	....	0 58	0 53
Barge Office, Savannah	24	8 14½	15 36	7 21½	5 03½	7.41	1.34	....	....
Cross Tides (Upper Grange)	28	8 37	16 29	7 52	4 33	7.48	3.02	0 13	1 25

Thirteen miles above Savannah the estuary is divided into three channels, which at Cross Tides, 4 miles above Savannah, unite into two, known as "Front" and "Back" Rivers. Front River skirts the city and then unites again with Back River. From this point to the sea the banks are low and marshy, and low marsh islands divide the flow into different channels. The bottom is of soft mud, or of mud and sand. Seven miles above Fort Pulaski, St. Augustine Creek opens a side communication with the sea from the south channel, through Tybee and Wilmington Rivers, as does also Lazaretto Creek, west of Tybee Island, near the mouth.

The portion of the estuary to be considered in the problem of the improvement of Savannah Harbor lies between Cross Tides and the sea. The problem is complicated by the discharge of the upper river, which may vary from 4 500 cu. ft. per second at low water to 400 000 cu. ft. per second during extreme floods, and which in floods carries large quantities of sediment; by the division of the thalweg into several channels, having varying velocities of tidal propagation and current; by the flow to and from St. Augustine and Lazaretto Creeks; and, finally, at the mouth, by the currents to and from the small estuaries opening to the sea close to the Savannah River, between Tybee Island on the south and Hilton Head Island on the north.

Prior to 1763, the depth on Tybee Knoll was 15 ft., and a good, clear channel was reported as far as Savannah. Between 1760 and 1822 much complaint was made of the shoaling of the river, caused by deposits of ballast and by drift and sediment from the upper river. As much as $100 000 was collected by a tax on shipping, which, under the State authority, was to be applied to clearing away wrecks, etc. In 1826 the United States made the first appropriation of $50 000 for the improvement of the harbor, to be expended by the Treasury Department. In 1830 vessels drawing 13 to 14 ft. of water were able to go to sea with favorable winds and tides, the depth just below Savannah having been 6½ ft. in 1816, and 7 to 7½ ft. in 1830. Other work was done by the United States under the direction of officers of the Corps of Topographical Engineers, and, at the outbreak of the Civil War, vessels drawing 17½ ft. were able to come to the city wharves by taking advantage of the tide. The channel was obstructed again during the Civil War by wrecks, cribs and torpedoes. These caused the formation of shoals, which decreased the high-water channel depth from 17½ ft. to

13½ ft. After the close of the war some of the wrecks were removed by the United States, and other work was done by the city authorities. In 1872 the United States Engineer Department resumed charge of the work.

The earlier works had included dredging, the removal of wrecks and the deepening of the channel by dikes and deflecting works. Several unsuccessful attempts were made to close the opening into Back River at Cross Tides, and the channel north of Fig Island. Finally, in 1857, the Fig Island dam was successfully built, and also a deflecting dike at King Island, above the city. None of this work gave permanent relief.

In 1873 General Gillmore submitted a project for the formation of a channel, 23 ft. deep at high water, from Savannah to the sea. This was to be accomplished by building a dam at Cross Tides, by widening the water-way opposite the city to 575 ft., and by dredging in the lower reaches, aided by such deflecting works as might prove needful. Work was carried on under this project as money became available. In 1881 the Cross Tides dam was completed, with very marked beneficial effects on Front River Channel. The project was successively modified and enlarged in 1879 and 1882, and work under it continued until 1890, when a revised and enlarged project was submitted by Captain Carter, based on a careful survey of the lower river.

This survey showed the general condition of flow to be about as follows (see Plate VI). Savannah River proper is entered by a flood volume of about 1 850 000 000 cu. ft., of which one-fourth enters the south channel. Below the mouth of the north channel the total flow on the north and south, past Oyster Bed, is 2 100 000 000 cu. ft., of which 300 000 000 cu. ft. enter Wrights River, and 1 390 000 000 cu. ft. the north channel.

Above St. Augustine Creek, the south channel flow, which had diminished to about 0.4 of its original volume, is increased by the flood inflow from the creek to 414 000 000 cu. ft. Above Elba Island the two streams from the north and south channels join and have a united volume of 1 100 000 000 cu. ft. After filling the tidal basin below Hutchinson Island, about .78 of the remainder passes up Back River and .22 up Front River. At Cross Tides the flow up Front River is increased from 114 000 000 to 140 000 000 cu. ft. by overflow from Back River.

On the ebb the flow through Front River above Cross Tides is 856 000 000 cu. ft.; 300 000 000 cu. ft. of this passes the dam into Back River, which just above Cross Tides has a flood volume of 165 000 000 cu. ft. Arrived at the head of Elba Island, the flow is divided nearly equally between the north and south channels. From the south channel about 350 000 000 cu. ft. passes out through St. Augustine Creek, and a smaller portion through Lazaretto Creek; so that, where the channels join, the ebb flow from the south channel is about one-half that from the north. The total ebb flow from the river is 2 570 000 000 cu. ft. Near the end of the north channel the flow from the river to the south of Oyster Bed is 1 450 000 000 cu. ft., about double that to the north, which has been augmented also by the ebb from Wrights River.

Captain Carter concludes that a mean ebb velocity of about 2 ft. per second is required, to secure permanence to the channel. He proposes so to adjust the cross-section of the river as to give a navigable channel through North Channel and Front River from the sea to Savannah, which shall have a depth at mean high water of 26 ft., and shall permit a free access to floods and, as far as practicable, a uniform velocity of 2 ft. per second for ebbs. In Front River the adopted width varies from 500 ft. at Cross Tides to 600 ft. at Kinsey Point, and 700 to 750 ft. at mouth of Wrecks Channel. In the North Channel the widths will vary from 1 200 ft. at the head of Elba Island to 1 870 ft. at Long Island crossing.

The principal factors of the proposed improvement are:

First.—The enlargement of Drakie Cut.

Second.—The entire or partial removal of King Island.

Third.—The construction of a deflecting jetty from Argyle Island.

Fourth.—The partial removal of Marsh Island and the closing of the channel north of it.

Fifth.—The construction of a training wall from Marsh Island to Kinsey Point and the enlargement of the river near there.

Sixth.—The construction of a training wall at Garden Bank.

Seventh.—Spur jetties or bank protection in the Wrecks Channel, and a deflecting jetty at Mackay Point.

Eighth.—The removal of a portion of Dam No. 15.

Ninth.—The closing of Duck Puddle.

Tenth.—The construction of shore protection and of training walls

between the wing dams in North Channel, from the upper flats to the Oyster Bed.

Eleventh.—The construction of training walls extending eastward from Cockspur Island and the Oyster Bed.

Twelfth.—Dredging is provided for between the Cross Tides and Tybee Roads.

The estimated cost of this improvement is $3 500 000, providing funds are regularly and adequately supplied.

Up to 1890, when the present 26-ft. project was adopted, the following sums had been spent on this improvement:

Prior to 1826, about $100 000, by the State;

1826–60, $374 000, by the United States;

1867–71, $157 000, by the City of Savannah;

1874, $193 000 (removal of war obstructions);

1872–90, $1 212 000.

Under the existing project there had been expended to June 30th, 1892, $346 000. The work since 1872 has increased the available high-water depth from 14.5 ft. to from 21 to 22 ft., and "the increase on the value of exports since the year 1873, when the work was begun, is proportional to the cube of the increase in the depth of the water during the same period."* The positions and lengths of the various works are shown on Plate VI.

Methods; Fig Island and Cross Tides Dam.—The necessity for increasing the depth of water in Front River by concentrating into one channel all or a portion of the water escaping from it at Cross Tides, and between Fig and Hutchinson Islands, was recognized as early as the close of the last century. Accordingly, efforts were made from time to time to close these channels by sinking wrecks in the waterway, and by building dams of crib-work, piling and of ballast stone, tightened with oyster shells, gravel and clay. The soft mud bottom, the erodible material of the shores at the abutments and the alternating flow in the two directions made these works particularly difficult to construct and maintain, and they were undermined and wrecked either during construction or soon after completion. It was not until the third or fourth attempt that the Fig Island Channel was finally closed, in 1853–54.

The Cross Tides Dike proved even more unmanageable. In 1876 it gave rise to an important decision by the United States Supreme Court

* Report of Captain Carter.

on the authority of the United States over her inland water-ways. Construction of the closing dam, which was started in 1876, was suspended by a temporary injunction, granted by the Supreme Court on the petition of the State of South Carolina, which objected to the interference that the dam would cause with the navigation of Back River, which formed the boundary between the States. The injunction was removed after the case had been heard, the Court deciding that the authority of the United States in the matter was absolute. The dam was to consist of two rows of piling braced together, the flow to be regulated by shutters in the openings in the upper row. Soon after the work was renewed in 1877, the partly finished structure was injured by a freshet, and abandoned.

In 1879 a new dam was started near the site. This was finished in 1881. Its foundation consisted of a mattress of brush and cane, ballasted with stone. It was brought to about the level of mean low water with rip-rap stone, except near the Argyle Island end, where, for 100 ft., there was a low-water depth over it of 6 to 8 ft. In 1882 the crest was raised to 3 feet above low water with brush mattresses and rip-rap. The increased pressure on the dam induced undermining and settlement, and in 1885 it was raised to mean high-water level again, with brush fascines and stone, and, the stability of the work having been threatened by the scouring of a hole 40 ft. deep by the overflow at the east end of the dam, an apron of log mattresses, 40 to 70 ft. wide, was placed along the base. As the log mattresses settled, the gaps made were filled with brush fascines and stone. Repairs were continued as needed until 1888, when the dam attained a stable condition, with a crest about 1.5 ft. above low water. The contract price of the dam, as constructed in 1879–80, was $9.47 per linear foot of apron, of an average width of 25½ ft., and $2.41 per cubic yard of rip-rap superstructure.

The effect of the dam on Front River was immediate. The average mean bottom velocity was raised from 1.75 to 2.37 ft. per second, and between 1879 and 1889 the cross-sectional areas and the mean depth increased 20 per cent. The difference of level on the two sides of the dam amounted to about 3 ft. This heightening of the low-water plane has caused a reduction (estimated to amount to 75 000 000 cu. ft.) in the tidal prism of Front River. In the new project this is to be made up by the enlargement of other portions of Front River.

The other dikes and jetties are shown on the map (see Plate VI). Almost all "are built of log mattresses of an average thickness of 15 ins. The mats are covered with from 4 to 9 ins. of brush and loaded with from 5 to 9 ins. of stone, the top course receiving about 13 ins. In profile the shore ends of the dams are at high water-line, or at the height of the adjacent shores. The crest then slopes down to about 5 ft. above mean low water, which height is maintained to within about 200 ft. of the outer end of the dam; the crest then falls gradually to the outer end, where a tow, or wider lower mat, is placed. Repairs, when needed, have in general been made by filling the holes with brush fascines loaded with rip-rap stone."*

The spur dikes for bank protection at Elba and Jones Islands are built of piles and brush as described below. The Oyster Bed training wall consists of a mattress foundation and a superstructure of rip-rap, having its crest at mean low-water level.

The latest specifications for the Savannah Harbor work describe three varieties of mattresses, either one of which may be used. The first is similar to that used in Charleston Harbor. The second is a brush fascine mattress, similar to those of the St. Johns jetties. The third is like the second, excepting that the top layer of fascines is omitted.

The training walls and spur dikes are to be built as follows : Two rows of piles, 6 to 8 ft. apart, will be driven, the piles of each row being 8 ft. apart between centers. They will be driven on straight lines, vertically, 16 ft. into the bed of the river and will be cut off 10 ft. above mean low-water level. Waling strips of 6 x 10-in. timber will be bolted to each pile, on the outer side of each row, 1 ft. above mean low water. At each second bent the rows will be tied together and braced with 6 x 10-in. timbers, drift-bolted to the piles and to the waling strips. The space between the piles will be filled up to half-tide level with brush fascines, weighted with 250 to 500 lbs. of stone to the running foot. At the ends of the spur dikes the banks, where necessary, will be sloped back to an easy grade and protected with brush fascines, ballasted with stone, or staked to the bank. On the channel side of training walls, close to the piling, will be placed mattresses, 15 to 20 ft. wide. The ends of the spurs and such other points as may require it will be protected by clusters of piles. The spurs and training walls will be braced at intervals by a 6 x 10-in. timber, abutting against a cluster of two piles 12 ft. in rear.

*Captain Carter, Rep. Chf. of Engrs., 1888-II-1021.

Since the work began, the prices for materials in place have been as follows: Log and brush mattresses, 43 to 85 cents per square yard; brush fascines, $1.40 per cubic yard; stone, $2.90 to $3.19 per cubic yard; pile-work, $1.50 per cubic foot; oyster shells, $1.29 per cubic yard.

Between 1872 and June 30th, 1892, 2 675 671 cu. yds. of material have been removed from the channel by dredging, at a cost varying from 15 to 19 cents per cubic yard. This, as well as almost all of the dike and jetty work, was done by contract.

Remarks.—The greater part of the increase of channel depth has been due to a judicious use of wing dams and training walls. The instability of the river-bed, and the accuracy with which the cross-sections must be regulated, is shown by the following incident, related by Captain Carter. In 1885 two spurs were built from opposite banks of the river at a shoal on which the original depth was 12 ft. Within three months after completion, a 15-ft. channel, 300 ft. wide, had been formed between them. Shortly after, the crests of the spurs were lowered to mean low-water level by a cyclone. Shoaling immediately began, and in a short time the original depth of 12 ft. was restored. In 1886 the dams were repaired. The additional depth was again scoured out and has been maintained since.

The cost of this improvement has been increased by the late change of project, which will necessitate the removal of some portions of works now in place. As this change has been necessitated by the demands of a commerce which has grown to its present proportions as a result of the improvement effected by the works, it may be granted that they have paid for themselves in full measure.

A history of this improvement would be incomplete without a notice of the careful survey of the river made in 1889–1890 by Mr. E. A. Gieseler, Assistant Engineer, under the direction of Captain Carter. In the report of this survey* the involved problem presented by the gauging of a tidal stream, flowing through several channels and receiving a varying fresh-water discharge, has been carefully and elaborately worked out. The methods followed are described in detail, and may well serve as a model for future work of that character.

From 1872–78 the work was under the charge of General Gillmore, with the following assistants in local charge at the work: Captain

* Rep. Chf. of Engrs., 1890-II-1265, and 1891-III-1507.

William Ludlow, Captain D. P. Heap, E. Sherman Gould, C. E.; Captain J. C. Post, S. L. Fremont, C. E.; Captain B. D. Greene, Lieutenant T. N. Bailey, and Lieutenant O. M. Carter. Since 1888 Captain O. M. Carter has been in charge, with Mr. A. S. Cooper as assistant.

St. Johns River Jetties.

The St. Johns River has the peculiarity of being the only large river on the Atlantic seaboard of the United States which runs from south to north through the greater portion of its course. Its total length is over 400 miles. In a portion of its course it is subject to marked changes of level due to excessive rainfall. These changes induce cutting of the banks and other characteristics of sediment-bearing streams. For its entire length it is, however, practically a chain of lakes joined by narrow reaches, as signified by its Indian name "Welaka." These lakes act as settling basins for the sand and silt brought from the narrow reaches above them, so that even above the influence of the tide, the St. Johns ceases to be a sediment-bearing stream.

The tide is felt as far as Little Lake George, 100 miles from the mouth. At Jacksonville, 23 miles from the mouth, the mean range of tide is 1.02 ft.; at Mayport, 1.7 miles from the mouth, 4.34 ft.; and at the mouth, 5.2 ft. At the mouth, between the jetties, the ebb currents begin from 1½ to 2 hours after high water, and the floods about 2½ hours after low water. The duration of the ebbs may be taken as 6 hours and 52 minutes, and of the floods, 5 hours and 33 minutes.

Though the channel depths of the river vary greatly, between Jacksonville and the mouth a least channel depth of 20 ft. is found, excepting through two reaches, aggregating in length 8.5 miles. The minimum depth is 12½ ft. At the mouth, the flood and ebb volumes of flow have been estimated to be about 1 200 000 000 and 1 700 000 000 cu. ft., respectively.

The entrance to the river is obstructed by a fan-shaped bar similar to that described at Charleston. In 1878 its length from shore to shore, measured along its crest, was 3½ miles, the most salient portion being about ⅝ mile to the seaward of the straight chord joining its shore ends. The mouth of the river was about opposite the middle of the bar. The river channel, with mid-depths of over 25 ft., passed from the entrance close along shore to the south for about 1 mile.

From this permanent, deep channel, one or more channels radiated across the bar to the sea, on lines between the axis of the river mouth prolonged and the south shore, shifting under storm action with great rapidity, to the bewilderment of the local pilots. It is related that on one Christmas Eve a small fleet of vessels, including one steamer, was lying inside the mouth, blocked on their passage out by the shoaling of the channel. All hands went on shore to celebrate, leaving the cook alone on the steamer. During the night a west wind with a strong ebb broke the steamer from its moorings and the terrified cook found himself drifting helplessly seaward to what seemed a certain death on the bar. His satisfaction may be imagined when he discovered that the breakers were passed safely, the vessel having followed a new channel, cut by the storm which had filled the old. This was promptly buoyed and became for the time being the ship channel. The low-water depth in the channel across the bar varied from 6 to 8 ft.

The bar is of sand, and is of drift and wave formation. The coast drift is in both directions, with a decided resultant movement to the south. The extent of the shoal to the north of the entrance is due largely to Fort George Inlet, ¾ mile to the north. The widest portion of the bar is to the south of the river mouth.

The first appropriation for the improvement of the channel over the bar at the mouth was made in 1852. Ten thousand dollars were expended in dredging in 1853–55, but the improvement was not permanent. In 1853 Lieutenant H. G. Wright (later Brigadier-General and Chief of Engineers, now retired) submitted a report, based on a survey made by the United States Coast Survey. The report describes the bar as a drift and wave bar, and recommends the deepening of the channel across it by confining the currents by two jetties, built on the shoals to the north and south, substantially in the manner adopted 25 years later. No action seems to have been taken on this report. The report is interesting, particularly in view of the early date at which it was submitted.

Between 1870 and 1873 $50 000 were expended in dredging operations. As reported from the first, these operations were not intended to afford more than temporary relief. Each long storm obliterated all traces of previous work. In 1872 General Gillmore reported that permanent improvement could be hoped for only by the application of the jetty system. He hesitated about recommending this on account of its great cost.

In 1878, after consulting with Mr. James B. Eads, C. E., the citizens of Jacksonville presented a memorial to Congress, requesting that a system of permanent improvement be adopted for the entrance to St. Johns River. With the appropriation of $10 000, made in that year, the necessary surveys were made. A project was submitted by General Gillmore in 1879, under which work since then has been carried on. Two curved jetties are being constructed, springing from the opposite shores near the entrance and converging until on the crest of the bar they are 1 600 ft. apart. From that point they are to be parallel through the length to which it may be necessary to prolong them. The jetty channel is located on the line occupied by the best of the temporary northern channels. The depth to be attained is 15 ft. at mean low water. It is expected that the jetties will maintain generally a depth sufficiently greater to allow a temporary shoaling from storm action. The jetties were to consist of a foundation mattress of logs and brush, with a superstructure of rip-rap. According to the original project the jetties were to be submerged. The present plans permit them to be raised to any necessary height.

On June 30th, 1892, the north jetty was 10 991 ft. long. All of the jetty except a shore connection, 360 ft. long, and a length of 225 ft. where there are two courses of mattresses, consists of a foundation of mattresses varying in width from 40 to 120 ft., with a superstructure of rip-rap. The shore connection is a pile, brush, and rip-rap dike. The level of the crest can be seen on the profile (Plate VII). Up to June 30th, 1892, 123 137 sq. yds. of mattress, 90 594 cu. yds. of stone, 5 819 cu. yds. of oyster shells and 565 cu. yds. of concrete had been used in the construction of the jetty.

The south jetty at the same date was 8 293 ft. long. The width of the foundation mattress varies from 20 to 120 ft. A second course of mattresses is laid for 3 209 ft., and other courses of varying length to a ninth, which is 40 ft. long. Since 1888 mattresses have been used only in the foundation course, the remainder of the jetty being built of rip-rap. Four sets of spurs were built at a narrow portion of the jetty. The crest heights can be seen on the profile (Plate VII). Up to that date 217 650 sq. yds. of mattresses, 94 925 cu. yds. of stone, 3 730 cu. yds. of shell and 218 cu. yds. of concrete were used in the construction of the jetty. The total cost of the work, including a survey of the upper river and a month's dredging by the steamer *Woodbury*, has been $1 003 000.

The jetties have deepened the channel over the bar to 11½ ft. in the south channel and 10½ ft. in the north channel. Work for deepening the shoalest portion of the reach between Jacksonville and the bar by dredging and the construction of dikes, under a project approved by the Chief of Engineers, is being carried on by the County of Duval, under the charge of Mr. J. H. Bacon, formerly U. S. Assistant Engineer.

Materials and Methods; Mattresses.—The mattresses used until 1888 were of logs and brush, similar to those used in the Charleston jetties. In the St. Johns work they proved very unsatisfactory. Where the bottom was irregular, the mattresses broke, and many logs were loosed from the binders and lost. The mattresses were not strong enough to be handled in a seaway and strong currents, and some were broken and lost before being placed. When in place they were frequently underscoured in positions where there was a strong current, or where a difference of head was developed, causing a settlement which amounted to 20 ft. at one point. They were not easily covered by sand, and so were long subjected to the ravages of the teredo. In shoal water the brush disappeared completely in less than two years, through wave action and the teredo. For these reasons they were discarded, and a brush fascine mattress was used, which, as finally adopted, is described in the specifications as follows :

"The mattresses will consist of a layer of closely compacted fascines of live brush * * * * crossed at right angles by a second layer of like fascines, placed at intervals of 6 ft. The brush must be carefully laid so as to break joints and make a continuous fascine extending completely across the mattress. The fascines must contain as much brush as may be required, and must be compressed tightly by an approved form of choker to a diameter of 9 ins., at intervals of 2 ft., where they must be bound firmly with iron wire of approved strength. The fascines must be firmly held between binding poles made of live saplings of yellow pine, or other timber of a kind approved by the engineer in charge. These must be straight and of slight taper and must be not more than 5 ins. in diameter at the butt, nor less than 2 ins. in diameter at the tip. They must be spliced together with long scarf joints in a manner satisfactory to the engineer in charge, so as to extend completely across the mattress. Either one or two layers of these poles will be used at the top and at the bottom of the mattress, as may prove necessary for holding the fascines until in place in the jetty and ballasted. The binders in each layer must be placed parallel to each other at intervals of 6 ft. * * * * The fascines and

binders must be firmly compressed and lashed together at intervals of 6 ft. in a manner satisfactory to the engineer in charge. Towing beckets, buoys and lines, and range masts must be placed as directed."

The mattresses are built on shore on ways consisting of parallel timbers about 6 ft. apart, supported on piles, with a slope toward the water of about 1 on 12, and with their lower ends at the level of high water. The tops of the ways are arranged for launching the mattress with as little friction as possible. One method is to have a longitudinal groove in the top 1 in. deep. The bottom and sides of this groove are smooth and coated with graphite, tallow or some other lubricant. In the grooves are laid strips of 2-in. lumber, with the bases and sides smooth and lubricated. These are fastened in place temporarily and have light lines attached, for drawing them ashore after the mattress has been launched. On the ways, at right angles to the timbers, is placed the first layer of binders, and on these, a second layer, forming a grillage with 6-ft. spaces. The binders are spiked together at each intersection. On the grillage, parallel to the top layer of poles (to reduce the distance from the sand when in place), is placed the lower layer of brush fascines. These must be of small brush, choked as tightly as possible before binding with a heavy rope and levers, as described for military fascines. When finished, they should be absolutely compact and hard where bound by the wire. Between the wires they should bulge out so as to extend to the base of the grillage. The fascines are jammed together in the mattress by levers. On this layer is placed the second layer at the 6-ft. intervals. On these comes the top grillage, with its intersections over those of the lower grillage. At each intersection of the lower grillage has been lashed a piece of manilla rope, ½ in. in diameter. This is led up between the fascines as they are placed. After the top grillage has been placed, the two grillages are drawn together by levers to the full strength of the rope, and lashed.

The mattresses are placed in the jetty with the lower layer of fascines at right angles to the jetty axis. The mattress as used has been 120 x 75 ft., the greater length (the side) being across the jetty. Towing beckets are placed at intervals across the ends. At the sides, at the extremities of the line which is to lie in the axis of the jetty, are placed range masts, long enough to have their tops 6 ft. above high water when in place, and also wood buoys, anchored to the mattress

with ropes, for use should the range masts be accidentally carried away. The mattress being finished, at the next convenient high water the temporary fastenings are removed from the slide strips, and a tug draws the mattress from the ways. The ends are immediately made fast to flats loaded with ballast stone, by lines running through the beckets and fastened to the flats in such a manner as to permit a gradual paying out. To increase the buoyancy of the mattress, the grillage poles are frequently barked and seasoned. At times, also, small flats are floated over the mattress and fastened to it.

Just before the end of the ebb, the tow, consisting of one tug, the mattress between the two flats, a rowboat for the inspector and a heavy rowboat with crew, for setting out anchors, starts. The start is so timed that the mattress will be in position at low water slack. Arrived nearly at the site, a line is passed from a mooring attached to a heavy anchor already in place inside the jetty, the tug casts off its line and the flats and the mattress are swung by the last of the ebb into position across the end of the jetty. Other anchors are run out, until the tow is held by from four to six anchors, placed at the diagonals, and one shoreward and one seaward. The lines from the anchors are passed around capstans on the flats, and the mattress is carefully adjusted by signals from the inspector in his boat, so that the inner range mast is close to the outer range mast of the mattress last placed, and the two range masts of the new mattress are in line with the shore range. Should any of the range masts be carried away, the corresponding buoys are used. At a signal from the inspector, the stone is thrown from the flats on to the mattress as rapidly as possible, the mooring lines being paid out as the mattress sinks. Just before the mattress touches the bottom, a last adjustment is made. After the mattress is once in place, it cannot be moved. The flats are then drawn together across the mattress, and the remaining stone is distributed as evenly as possible over the surface of the mattress. Soundings are taken by the inspector just before and just after the mattress is placed. After it is in position and ballasted, transit observations from shore on the range masts give the necessary data for plotting its position on the progress charts. Five feet leeway is allowed the contractor in placing the mattress in the designated position. An expert foreman will place his mattress within this limit with ease.

The brush mattresses are so strong and flexible that they can be

handled in a seaway which would wreck a log mattress. The passage of a wave under the mattress can be followed easily by the undulation. The upper layer of fascines with its grillage forms a series of shallow cribs which assist in holding the stone. No under-scour has been observed with the long brush mattresses of the St. Johns work. The length is also sufficient to make an efficient apron along the sides of the superstructure. To decrease the chance of scour along the edge of the mattresses and to increase the width of apron along the inside of the jetty, the range masts are placed alternately 45 and 55 ft. from the outside or sea ends of the mattresses, thus bringing the inside ends alternately 75 and 65 ft. from the jetty axis. The use of mattresses above the bottom course was found to be inadvisable, the loss by the teredo was too great. Wood cannot be used in the jetties excepting where it quickly gains protection from the sand.

Experience at St. Augustine and St. Johns River has shown the approximate cost of a 120 x 75-ft. mattress to be as follows:

2 747 cu. yds. brush, labor at 15 cents per hour.....	$57 96
Hauling to fascine rack with cart and driver, at 25 cents per hour.....	110 59
Labor of making and handling 9 660 ft. of fascines at 15 cents per hour.....	96 60
Cost of 8 906 linear feet poles, delivered at ways.....	60 00
600 lbs. 60 D nails at $2 60 per 100.....	15 60
313 lbs. $\frac{1}{2}$-in. Manilla rope at $13\frac{3}{8}$ cents per pound.....	41 86
426 lbs. No. 14 iron wire at 14 cents per pound.....	19 17
Labor of assembling mattress at 15 cents per hour.....	144 27
" launching " " "	21 50
" sinking " " "	27 00
Superintendence at $75 per month.....	18 75
Total.....	$613 30

or $61\frac{1}{3}$ cents per square yard.

The contract price for log and brush mattresses in place varied from 54 to 75 cents per square yard, and of brush fascine mattresses in place from 70 to 74 cents per square yard.

Stone.—Where the cross-currents were not too strong and below low water, the light Florida limestone was found to answer for the super-

structure. Where exposed to wave action and strong currents, a heavier stone from the North had to be used. The stone was all placed by hand. It is bought by the ton, the weight being determined by the displacement of scows or flats. At first all stone was bought by the cubic yard, but the impossibility of accurate measurement of rip-rap, and the frequent disputes as to volume which this method entailed, caused it to be discarded. The following method was devised, to prevent errors in gauging the flats arising from wave action and the varying density of the water at the mouth of the river.

A small well is built through each end of each flat, close to the keel and just inside the rake. Immediately before a loaded flat is taken to the jetty, a tube, 4 ins. in diameter, with the bottom pierced with a small hole, is lowered into each well in succession. The top of the tube is flush with the deck, and through its lid a rod passes freely, having a float attached to its lower end. Distances from the water-line on the float are marked on the rod. As soon as the water in the tube ceases to rise, which will be when the mean level of the water outside is attained, the reading is taken; at the same time the density of the water is read with a salinometer. With these readings the displacement of the scow is obtained from a table previously calculated for that scow. As soon as all of the stone which has been accepted has been unloaded, the scow displacement and density of water are measured again. The difference gives the weight of stone. The method has been found to be easily applied and accurate. Since the flats have to be loaded evenly for safety in the seaway, the two wells are found to give the same results in all practical cases as would be found from four wells at the corners.

Shell.—Oyster shells were used for a time as hearting. When they can be deposited quickly and protected from wave action, they are found to make a cheap and tight hearting. Loose shell dumped near a hole under the jetty quickly stopped the flow and caused the sand to collect.

The contract price for stone varied from $3.10 to $4 per cubic yard of 2 700 lbs.; and from $2.07 to $2.57 per ton of 2 000 lbs. Under the specifications for purchase by the short ton a lighter stone was allowed to be used, and the stone delivered consisted of Florida limestone, weighing from 2 000 to 2 100 lbs. per cubic yard, and Northern stone, which weighed from 2 400 to 2 700 lbs. per cubic yard. The

price of oyster shell varied from $1 to $1.40 per cubic yard, according to the position where used.

Shore Connections—North Jetty.—The inner end of the north jetty, as first built, was twice flanked by the sea, and a dangerous cutting of the beach took place. In 1887 the channel was closed and the jetty carried beyond high water-mark by a pile dike. This consisted of two rows of palmetto piles, 6 ft. apart, tied together and braced. The piles were driven by the aid of the water-jet. The space between the piles was filled with stone, resting on a log mattress foundation. The strong currents induced great scour and cutting of the beach as the piles were placed, and after the hearting was in position, under the dike. The mattress proved too stiff to follow the lowering sand, and the hole under the dike attained a depth of 10 to 15 ft. Finally, the mattress, where necessary, was torn out and the holes filled with brush in bundles and rip-rap stone. Wings of rip-rap were built on the two sides of the dike, to stop the scour of the racing waves. Within a year the beach had built to the level of the top of the dike, the sand advancing from the north over the lowered beach like a great wave. The dike is now buried completely.

The south jetty shore extension was made with rip-rap, capped with concrete blocks, over the old mattresses. Immediately after the work was finished a fill began on the south side, while the north side was cut, showing that the sand on this side was supplied from the south. By removing a portion of the jetty capping, just beyond the high water-line, a breach was made about 20 ft. long, with its crest at about half-tide level. A large supply of sand was swept through this breach at each flood.

Sand Catches.—Cheap and efficient sand catches were made by an ordinary post and rail fence. The posts were set up, and a couple of boards, with an interval an inch wide between them, to reduce the wind eddy, were nailed on just above the sand level. As the sand built up, other boards were added, until the desired height was reached. This style of sand catch was used earlier, at the Cape Fear work. Another efficient catch was made from old cement barrels, filled with sand.

Capping.—The experience at Cape Fear had shown the necessity for smooth, easy slopes for the portion of the jetty exposed to wave action, where very heavy blocks could not be obtained. Accordingly, when, in 1888, it became necessary to raise the level of the inner end of the

north jetty above the low-water level, in order to build out the beach and to strengthen the shore connection, recourse was had to light blocks of concrete, since stone in proper sizes was too costly. These were laid with a crest 2 ft. wide, 5 ft. above the level of mean low water, and side slopes of 1 on 3. The blocks had an exposed surface of 4 × 2 ft., and were 18 ins. deep. To permit construction to be carried on during the falling as well as during the rising tide, and to allow each block to settle freely, all the sides were made vertical, giving a lozenge-shaped vertical section, perpendicular to the jetty axis. To break joints properly, the blocks were laid herring-bone fashion, as in brick sidewalks. Each block weighed 1 700 lbs. When left loose on top of the jetty, they were moved by the waves easily. None were ever disturbed after having been placed. The heaviest waves slipped smoothly over the slopes without their power having been developed. The joints between the blocks and the lewis holes through them were found advantageous for permitting the escape of air from the rip-rap hearting during wave action. Later, a small section 6 500 ft. from shore was capped with concrete blocks, weighing 1 600 lbs., of hexagonal horizontal section, with vertical sides 18 ins. deep, and laid with side slopes of 1 on 2. These proved easy to handle and to place, but were just under the limit of weight. One or two blocks on the inner slope were jumped out of place during storms.

Tides and Currents.—The mean range of tide at the mouth of St. Johns River has been stated to be 5.2 ft. The tidal curves given on Plate VIII show the tidal range on June 5th, 1890, and the mean velocities on the same date. Station No. 1 was on the crest of the bar, on the edge of the channel, 2 000 ft. outside of the outer end of the south jetty. Station No. 2 was in the south jetty channel, 2 000 ft. inside the outer end of the south jetty. Station No. 3 was in the north jetty channel, directly opposite the angle in the jetty. In 1879 the mean flood and ebb velocities in the river at Mayport were estimated to be 1.6 and 2.2 ft. per second, respectively. The tidal curves of Plate VIII may be considered to be fairly typical. The current directions at Station No. 1 were inclined toward the south jetty channel during flood, and away during ebb. At Station No. 2, south jetty channel, the directions were in during flood, and out during ebb. At Station No. 3, north jetty channel, the directions were in during flood, and out during ebb. At this last station the influence of

the flow across the jetty during both flood and ebb was seen more plainly than at Station No. 2. The slight development of flood velocities and the strong ebb velocities at all of the stations will be noted. In general, it has been observed that the flood pours in across the jetties from both sides and through the opening between the jetties, and that the high flood velocities are not found until the flow is concentrated in the interior channels; that the ebb follows defined channels as much as possible, is strongest in them, and is the controlling current in the channels across the bar; that head and velocity of ebb currents are decreased as the distance from the mouth increases, by the spill over the tops of both jetties; that the submerged jetties control the bulk of the ebb flow, guiding it with least loss of head when the current is parallel to them; and that the maximum flow across the jetties on both ebb and flood is dependent on the direction of the wind, that is, a strong wind from the north will increase the relative flow across the north jetty during floods and decrease it during ebbs, and the reverse.

No diminution of the tidal range or volume in the river has been observed since the work began.

Jetty Location and Sand Movement.—The work at the mouth of St. Johns River illustrates clearly the fact that the drift and wave bars of our southern coast can be molded at will by the engineer. A new channel can be formed on any desired line. The cost of forming and maintaining this channel will vary with the location and form given the jetties, and the best position will be that in which this total cost is least. Many conditions must be considered when the location is selected, and, the location having been made, there remains the choice of methods for compelling the necessary scour; so that it is not surprising that engineers should differ. After a work has been started, the knowledge gained by the work itself may show that another plan might have proved more economical and make later criticism easy. The plan adopted by General Gillmore for the St. Johns improvement is similar to that adopted earlier at Charleston, and is nearly on the lines recommended for parallel jetties by Mr. James B. Eads, C. E., to the citizens of Jacksonville.

The history of the sand movement between the jetties may be summarized as follows: In 1879 (see Plate VII) the project was formed. There were then two channels across the bar, one leading out between

the lines of the proposed jetties, and one, slightly deeper, on a straight line running southeast from the mouth. The north jetty is so placed as to run on nearly the shortest line, in the shoalest water, from a safe point on shore, north of the river mouth, to the north side of the channel over the bar. The proposed south jetty crossed the permanent deep channel leading to the south along the coast, and converged toward the north jetty, until at the channel over the bar, where the work was required, the desired contraction was attained, when it became parallel to the north jetty.

In 1883 the north channel of 1879 had been closed by a sand bank, bare at low water, reaching to the site of the south jetty, and the sailing line was across the south jetty, through the south channel. The north jetty was too short to have any effect beyond the development of a current around its ends, cutting back the beach. The south jetty foundation was extended to 5 000 ft., and, excepting in the sailing gap where an 18-ft. channel was left, it was built nearly to low water. From its position, it acted as a partial dam, directly across the main channel. The effects were: first, a portion of the ebb flow of the ship channel was deflected to the northeast; second, the channel shoaled slightly midway between the jetties; third, there was great scour at and near the sailing gap; fourth, a portion of the dammed-up water had passed out, close to the south jetty, cutting off the edge of the sand bank (Wards Bank) and forming a narrow channel directly seaward.

In 1885 the channel to the north across the line of the north jetty had become more clearly defined; the shoaling of the "middle ground" in the ship channel had continued, and the channel north of the south jetty had enlarged. The north jetty had just been extended from both ends and its effects had not yet showed themselves.

In 1886 the middle ground had shoaled to 14 ft.; the channel to the north had grown and had undermined the end of the north jetty. Its inner end was also flanked. The south jetty channel had enlarged and become the main ship channel. The shoals north of the south jetty had grown to their greatest size.

In 1888 the old sailing gap in the south jetty had been closed for over a year. The middle ground had shoaled to 10.4 ft. The inner end of the north jetty had been secured, and the beach there had begun to build. The north jetty had been extended to stop a portion of the

flow across its line, but the extent of the loss from the ebb currents there is shown by the scour along and in advance of its site. The futility of the expectation of building the jetty in shoal water had been shown by the scour, produced by the jetty itself as well as by the water diverted across it by the damming action of the south jetty. The north jetty had begun to turn a portion of the flow which formerly crossed its site in the direction of the bar channel. A portion of Wards Bank had been scoured away. The south jetty channel had widened and deepened, and the least depth across the bar was 13 ft. South of the south jetty there had been a marked shoaling in the old channels.

By 1890 the north jetty had been extended to the same length as the south. The effects of the 1890 work are seen in the map for 1891, in the straightening of the old permanent channel, just outside the river mouth; in the disappearance of Wards Bank and the opening of the new straighter sailing line between the jetties to the north of the middle ground shoal, on which the depths had decreased to 9.4 ft. Unfortunately, in October, 1889, work had to be suspended, owing to a lack of money, and, during the suspension, the jetty channel was forced by the northeast gales to the south, across the line of the south jetty. This bending of the channel has been a source of great difficulty since then. The only effective work to be done was to extend the south jetty. This could not be extended without closing the commercial entrance to the port to an unwarrantable extent. At the same time the scour through the channel deepened the site over which the jetty must be built, and this increased its height and cost. Under these circumstances work has been confined to stopping the escape of water around the end of the north jetty by a slight further extension, by raising the jetties to the level of mean low water, and by pushing the south jetty gradually seaward.

The fall and winter of 1891–92 was unusually stormy, so that on the map of 1892 the channel is found pushed far to the south, and the entrance difficult. On the other hand, the greater portion of the sand which formerly had obstructed the water-way between the jetties is found to have been scoured away. The deep channel from the river extends in nearly a straight line as far as the end of the south jetty, and the north jetty channel extends with a depth of 12 ft. to within 200 ft. of the outer slope of the bar. Once this channel is opened, it

will be a comparatively simple matter to control the flow sufficiently to obtain the required depth across the bar.

Remarks.—The six years' experience of the writer at this work has led him to the following conclusions. In a work under conditions similar to those existing at the mouth of St. Johns River (where the tidal flow is ample, and where the sand movement is large and from the north), two jetties are required. Their location should be such that as much advantage as possible may be taken of any conditions which permanent deep channels prove to have had a controlling power. To this end permanent deep channels should be followed, as far as consistent with economy in jetty length and construction and with a proper direction for navigation purposes. When permanent natural channels must be crossed, they should be deflected and not dammed, so that the channel first scoured by the work shall be in or near the position of the proposed channel.

The jetty on the side opposite the source of the moving sand, in the case in point, the south, probably will be always the guiding jetty and the channel probably will skirt it, at least through the most precarious portion of its course. Through this portion of the course it should be straight, or concave toward the channel. The north jetty will be needed to prevent the loss of water through false channels across its line. These may be formed by the excess of head before the main channel is fairly opened, or by the deflection of the main channel during storms from the south, the north jetty will act, to some extent, also as a barrier against moving sand; but unless it be given an excessive height, this barrier must soon be crossed. If the necessary height be given, where the volume of moving sand is as great as along the Florida coast, the building out of the north shore may entail a speedy extension of the jetties, as well as increased first cost due to the great strength required for a breakwater, such as this then becomes. When the moving sand does cross the north jetty, it still remains as a solid core, necessary to prevent the formation of false channels across the sand dike. If the south jetty be prolonged sufficiently, it will be easy so to proportion the width of entrance to the tidal prism of the basin within as to maintain velocities sufficient to sweep into deep water the sands which encroach on its northern edge.

The height of the jetty should be sufficient to control the ebb flow to the required extent, and no greater. An increase of height calls for

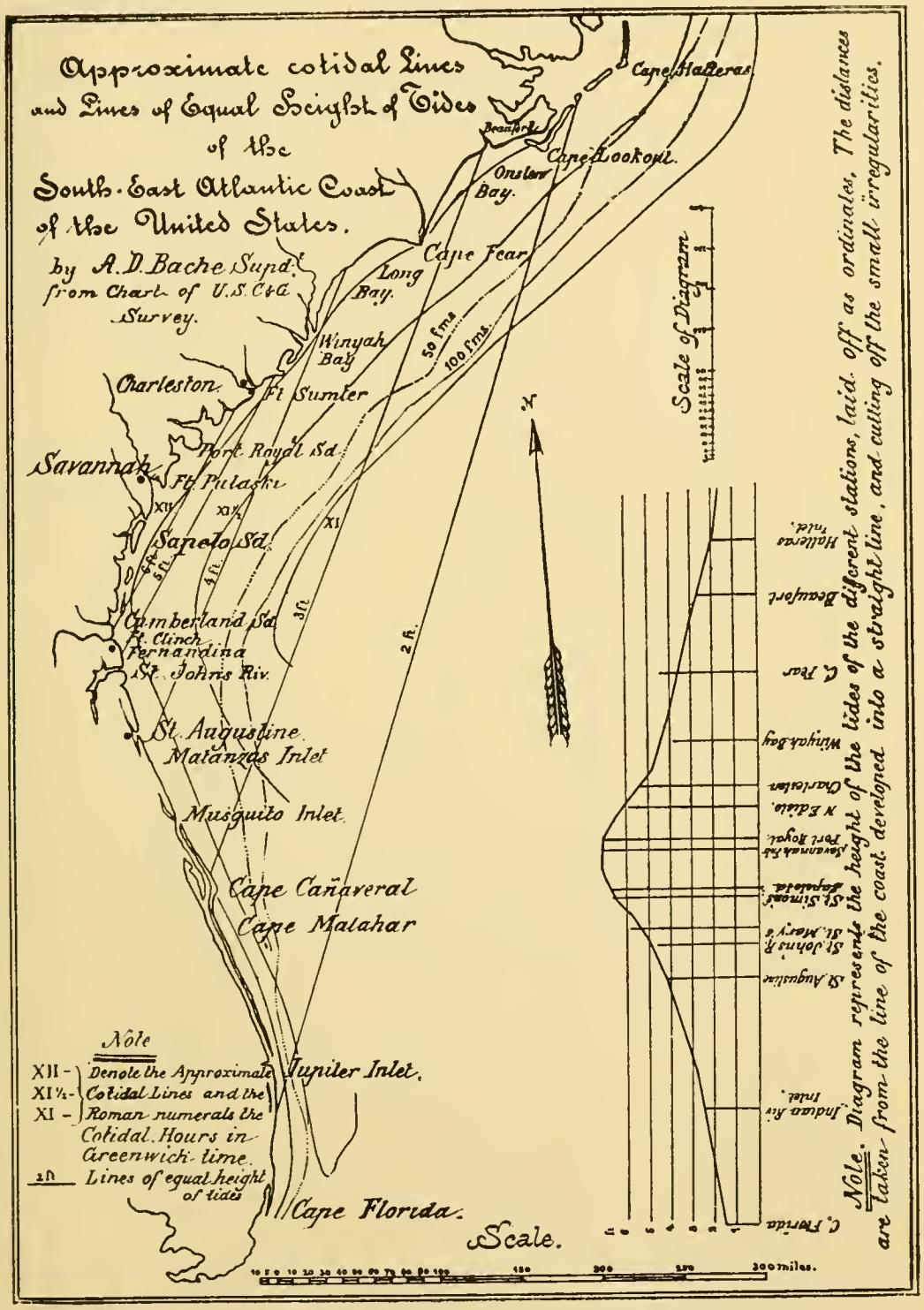
a rapid increase of strength to resist the greater amount of wave force which must be met and absorbed by the jetty. Where an increase of tidal basin is not required, the jetties should run on the shortest line to that point beyond the entrance at which the condition of the natural channel shows that the ebb currents require aid to maintain the channel depths. An increase of tidal basin, therefore increased power at the bar, may be obtained where needed by a wider divergence of the inner ends of the jetties.

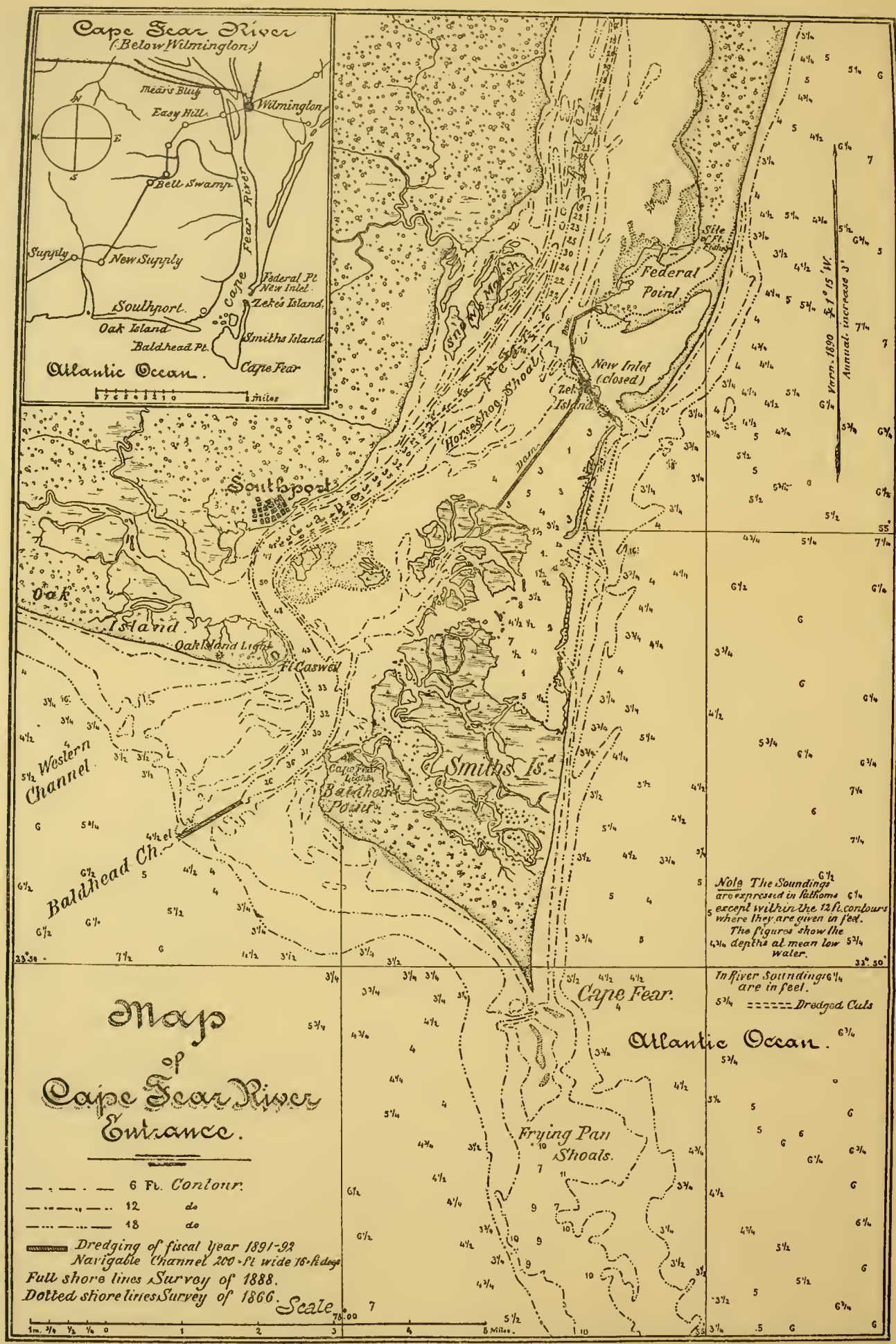
Like all the works along the coast, the St. Johns work has been hampered by irregular and insufficient supplies of funds. The immediate needs of navigation had to be provided for. It was impossible for the engineer in charge to foretell when, if ever, a future appropriation would be made. It was therefore impossible to carry on continuous work with the most economical methods, or to meet emergencies as they presented themselves. Like most unwelcome things, they seemed to have the faculty of coming forward exactly at the wrong time.

The ultimate height and length of the jetties will be controlled by the necessities of the work. The marked difference in level of the planes of mean flood and ebb flow make easier the problem of controlling the ebbs without too great an interference with the floods. The work already done by the jetties has been enormous. Up to June 30th, 1892, the total scour has been about 4 500 000 cu. yds., and the cost of removal (the cost of the jetties) about 21 cents per cubic yard, while the cost of dredging in 1872–73 was over 50 cents per cubic yard. A portion of this material has been deposited beyond the crest of the bar in moving it seaward, but the greater portion has been passed to the south. Each year shows a marked gain of channel length on the bar crest, and it cannot be long before the required depth is attained.

This work was under the charge of General Gillmore from 1869 to 1885; of Captain W. T. Rossell from 1885-86; of Captain W. M. Black from 1886–91, and, since then, of Major J. C. Mallery. General Gillmore's assistants were Lieutenant W. L. Fisk, Captain J. C. Post and Captain W. T. Rossell. The writer is greatly indebted to the entire staff of the work for most interested and efficient assistance. His principal assistants were Messrs. A. W. Barber, D. B. Dunn, J. W. Sackett and J. H. Bacon and Lieutenant D. D. Gaillard. Major Mallery's assistant is Mr. E. W. Gieseler.

VOL. XXIX, No. 610.
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE I.





VOL. XXIX, No. 610.
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE II.

VOL. XXIX, No. 610
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE IV.

Profiles from mean Soundings

Profile of 1882.
" 1887.
" 1891.
" 1892.

Near the North Jetty.

Mean low water

Note. Each profile shows the mean of the soundings of the designated longitudinal third of the total area between the jetties

Midway between Jetties.

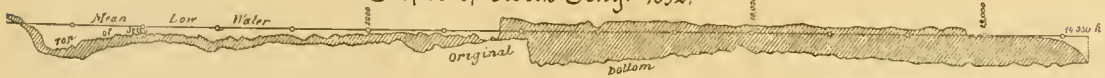
Mean low water

Vert Scale

Near the south Jetty.

Mean low water.

Profile of North Jetty. 1892.



Vertical Scale for Profiles of Jetties.

Profile of South Jetty. 1892

Entrance to Charleston Harbor S.C.

from U.S. Engrs Survey.

March to June 1892.

Scale of Map

Horiz Scale of Profiles

18 Ft Contour
15 " "
12 " "
9 " "

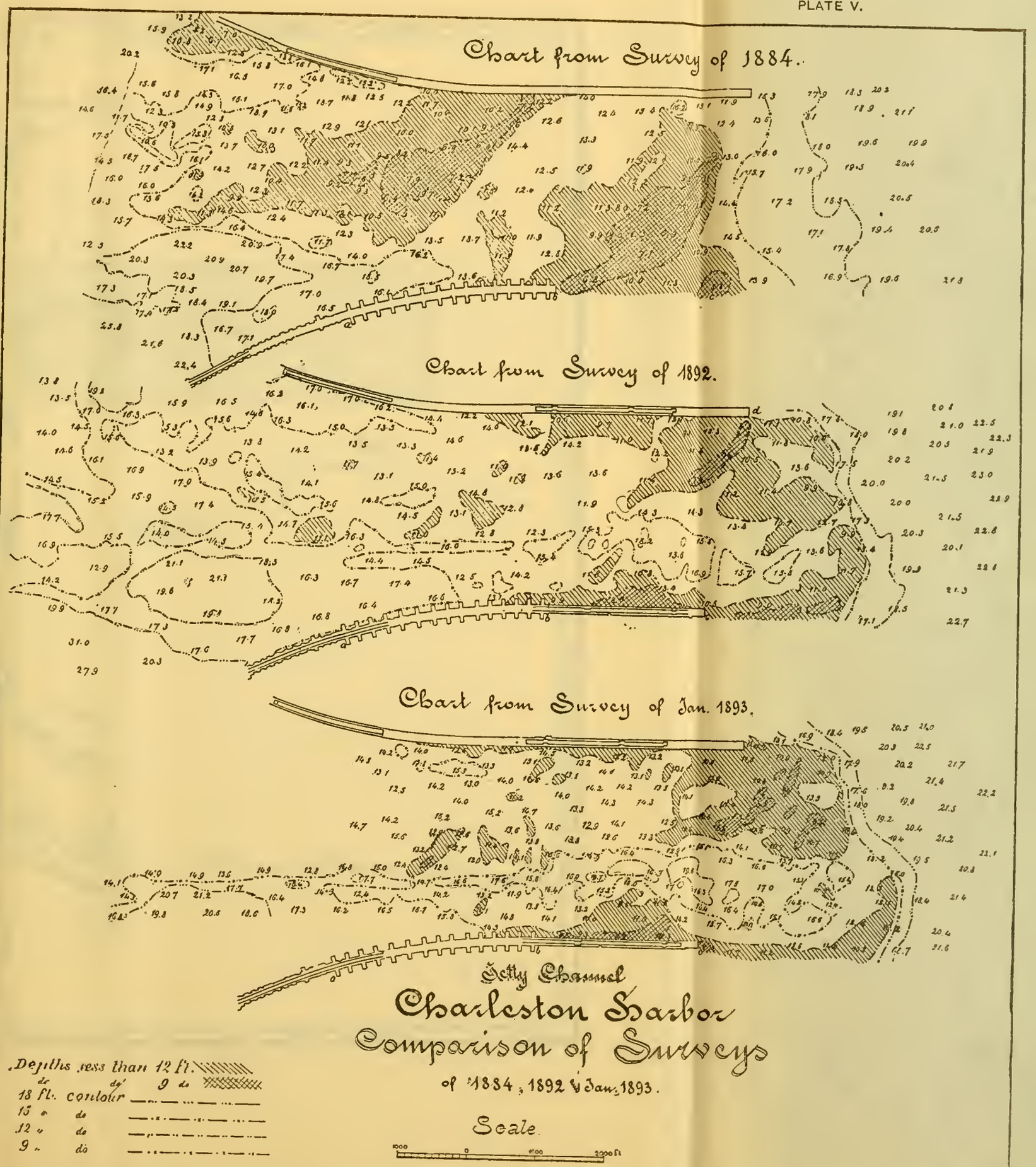
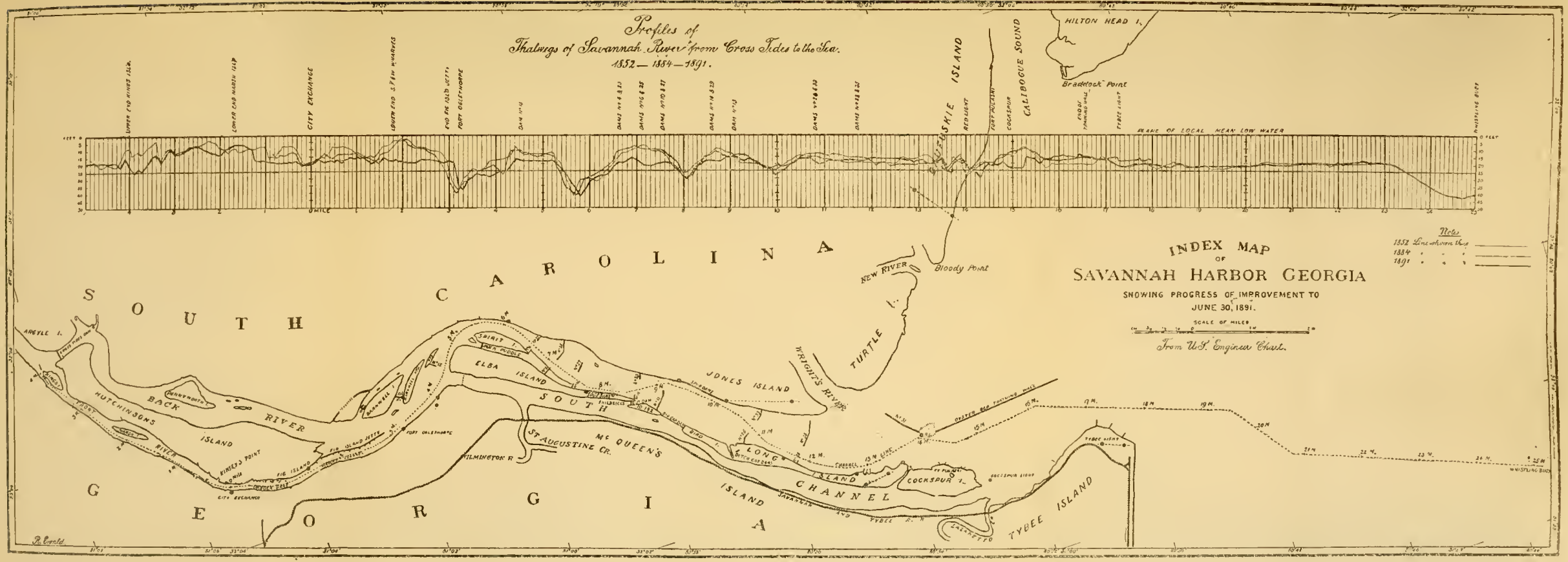


Chart from Survey of 1884.
Chart from Survey of 1892.
Chart from Survey of Jan. 1893.
Folly Channel
Charleston Harbor
Comparison of Surveys
of 1884, 1892 & Jan. 1893.
Depths less than 12 ft.
18 ft. contour
15 " do
12 " do
9 " do
Scale.

VOL. XXIX, No. 610.
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE VI.



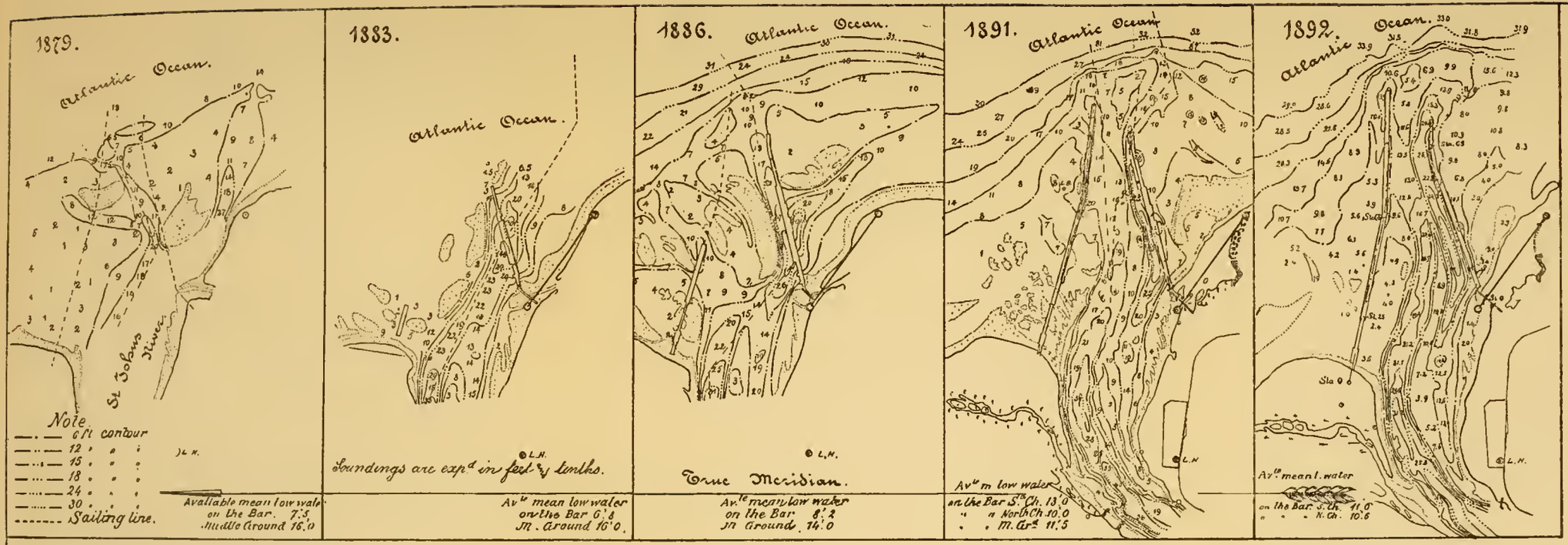
VOL. XXIX, No. 610.
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE VII.

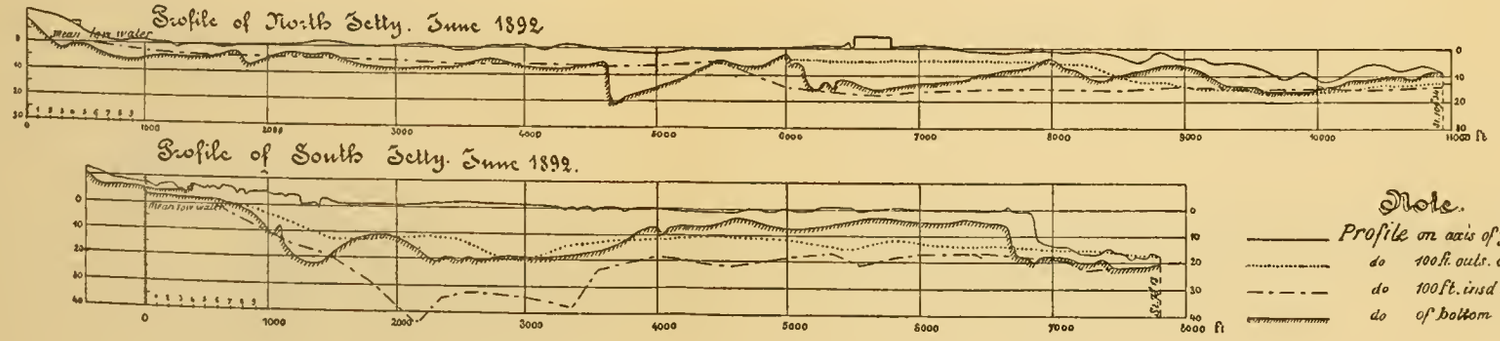
Improvement of St. Johns Bar Florida.

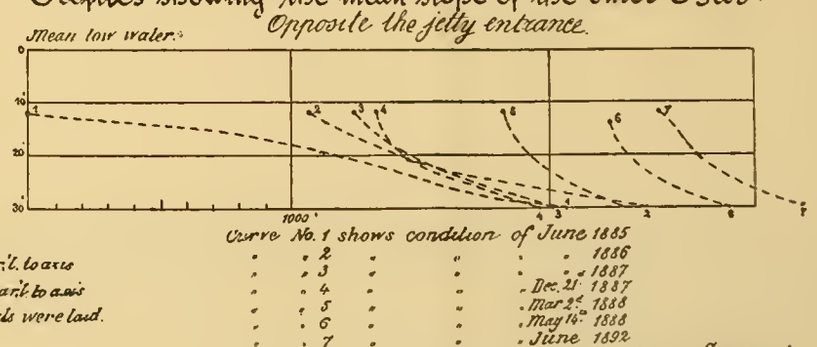
Comparative Charts showing the progress and effects of the improvement.

From U.S. Engineer Charts.

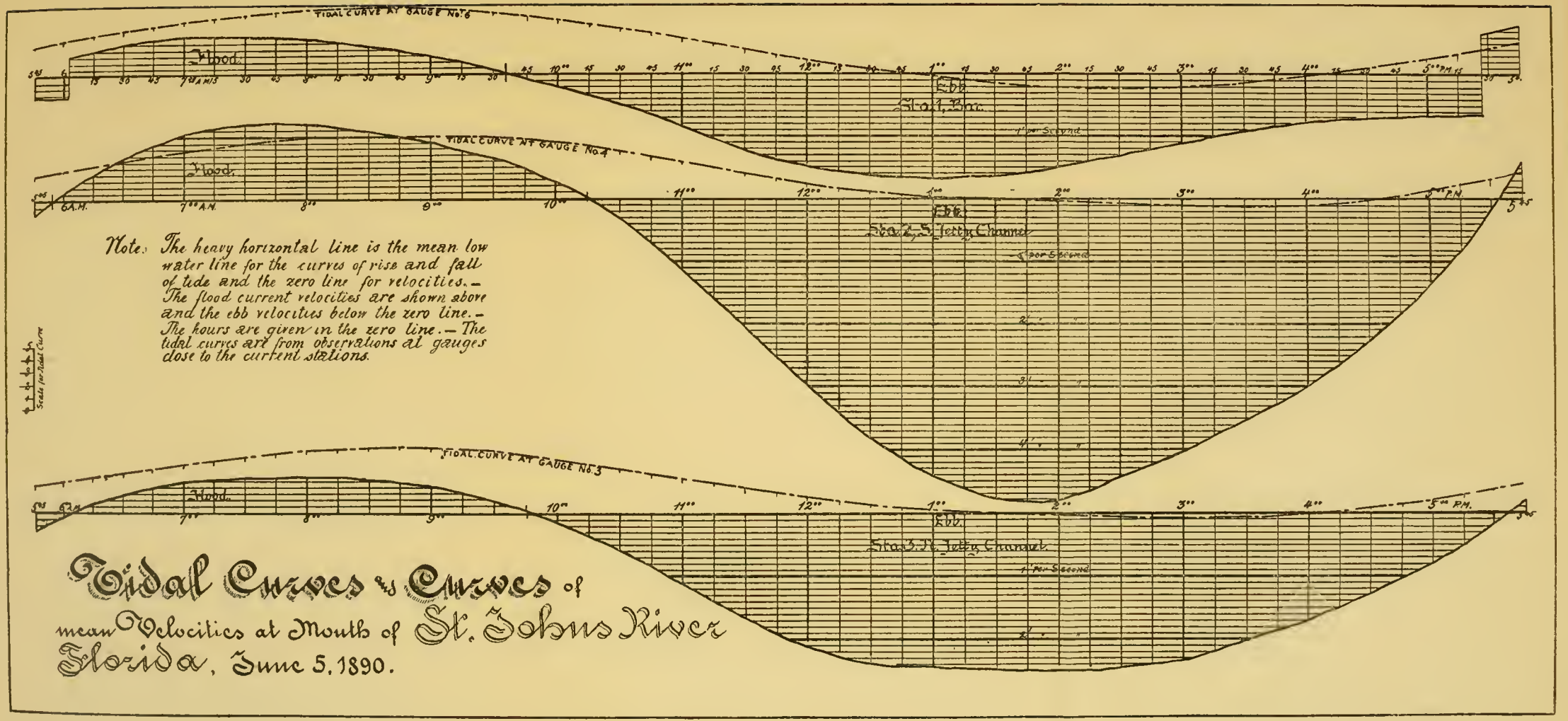
Scale







VOL. XXIX, No. 610.
TRANS. AM. SOC. CIV. ENGRS.
BLACK ON IMPROVEMENT OF HARBORS.
PLATE VIII.



Note. The heavy horizontal line is the mean low water line for the curves of rise and fall of tide and the zero line for velocities.— The flood current velocities are shown above and the ebb velocites below the zero line.— The hours are given in the zero line.— The tidal curves are from observations at gauges close to the current stations.

Scale for Tidal Curve

Tidal Curves & Curves of mean Velocities at Mouth of St. Johns River Florida, June 5, 1890.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

611.

(Vol. XXIX.—August, 1893.)

THE REARRANGEMENT OF RAILROAD TRACKS AND STATIONS IN COLOGNE, PRUSSIA.

By F. LOHSE, Eisenbahn Bau und Betriebs-Inspector, at Cologne, Prussia.

Translated from the German by MANSFIELD MERRIMAN, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Cologne, the third city of Prussia in respect to population, has, inclusive of the suburbs, over 300 000 inhabitants.

In consequence of the demolition of the old fortifications in 1881, and the establishment of a new boundary about 500 m. (1 640 ft.) distant from the old one, Cologne has grown very rapidly in the last 10 years, the increase in population being about 60 000. Not merely its

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

population, but also its extensive business interests and the commercial activity of its inhabitants, place Cologne at the head of the cities of the western provinces of Prussia.

The commerce of Cologne is partly that of the Rhine, about 500 000 tons per annum; but far more important is that of the railroads centering there.

Cologne is the terminus of three important railroad systems, viz.:

1. The lines on the right bank of the Rhine (to Holland, Hamburg, Berlin and the North).

2. The lines to Aix-la-Chapelle and Crefeld (to Belgium, Holland and England).

3. The lines to Bingen and Trier (the principal connection with the South).

The traffic of these lines was in the old arrangement provided for by two tracks through the main passenger station and by a few sidings. Since these tracks had no essential enlargement for 30 years they were inadequate to accommodate the increasing traffic. At present 82 passenger trains depart daily from the main passenger station, and 78 arrive; to these must be added many freight and other trains. The annual passenger business may be estimated at about 5 000 000 persons, of which 1 000 000 can be counted as of the city. Since almost all trains are made up in Cologne, and few pass through, the large through traffic must also be provided for, and it is astonishing that it was possible to do this so long in the old station in a systematic manner.

A second unfortunate condition of the old railroad tracks lay in the numerous grade crossings of streets. It was, of course, understood that in the new construction work these should be abolished or avoided.

Concerning the freight traffic the condition of things was similar, particularly because an extensive through traffic was controlled here. At the freight and switching station, Gereon, the switching reached the total annual amount of 1 000 000 cars, and in active seasons more than 4 000 cars were switched during 24 hours into their respective places. But this was the limit of possibility, while the traffic continually kept on increasing.

All these circumstances demanded an alteration of the layout, and

this indeed had been planned nearly 20 years ago by the former owners of the railroads, the Rhine Railroad Company and the Cologne and Minden Railroad Company. In consequence of the purchase of the lines by the Prussian Government in 1880, the opportunity for this rebuilding and improvement was materially hastened, so that in 1883 the necessary funds were voted by the Prussian House of Deputies.

I. The New Railroad System in General (Plate 1).

At the time when the preparation of the plans for the new system was begun, the demolition of the old fortifications, in order to extend the limits of the city, was in progress.

In consequence of this, the question arose whether the main passenger station should remain in its old location near the cathedral or should be transferred to the new part of the city. Several plans and estimates were made, but the final decision was in favor of the old location. To this condition and to that of the avoidance of grade crossings, by elevating the tracks above the streets, the entire plan was subordinated. There were many difficulties in carrying out the second condition, particularly with Eigelstein Street, back of the passenger station. This street had to be depressed about 2 m. (6.5 ft.), and the tracks were laid on the Rhine Bridge on a grade of 1 in 275, while the entire tracks of the station were laid on a grade of 1 in 400, in order to give the necessary heading of 4.65 m. (15.2 ft.) above the surface of Eigelstein Street.

On the other parts of the lines the steepest grade of the main track is 1 in 200, and the smallest radius is 300 m. (984 ft.).

Inside of the former city limits the old roadbed was utilized and widened, so that instead of the former double track three double tracks could be laid. One double track is devoted to the trains toward Bingen and Trier, another to those toward Aix-la-Chapelle and Crefeld, and between these are two tracks for the connection of the main station with the "traffic station" (Betriebsbahnhof).

At the traffic station the empty passenger cars are side-tracked and cleaned. There all the business in connection with fast freight traffic and with the through mails is conducted.

Hence, in the old city the railroad consists of six tracks which are supported by a viaduct or elevated substructure. Outside of the old

city, on account of the less value of land, earthen embankments are used for the roadbed.

The tracks of the Aix-la-Chapelle and Crefeld line soon leave the limits of the city and join the old line, while those of the Bingen line are laid close along the new ramparts until they join the old road.

On the last-mentioned line there are two passenger stations, West Cologne and South Cologne.

For the freight traffic there was erected a large freight and switching station, partly on the location of the old freight station. This is made accessible to the trains from and to Bingen and Trier by a branch connecting with the stations at West Cologne and South Cologne. For the lines toward Aix-la-Chapelle and Crefeld the freight tracks branch off near the ramparts at the point where the main tracks diverge to these two places. For the traffic on the right bank of the Rhine, a connection is made at Gladbacher Street near the passenger station, West Cologne.

To replace the old freight station, Pantaleon, a new freight station was erected at South Cologne, near the passenger station of that name. For the connection between the freight stations Gereon and South Cologne there is a special third track, which later will be extended to the improvements now in progress along the harbor.

II. The Main Passenger Station Near the Cathedral.*

(*a*) *Reception and Waiting Buildings* (Plates II, III, IV, V, VI).—The following fundamental conditions are established for the larger of the new passenger stations of the Prussian railroads:

1.—Passengers are not to be allowed to cross the tracks.

2.—The movement of baggage and mails to be on different platforms or passages from that of passengers.

3.—The distances traveled over in the station by passengers to be the shortest possible, regard being had to ascents and changes of direction.

The conditions 1 and 2 could be fully satisfied in the main passenger station in Cologne, but 3 could only so far as the relations of the surroundings allowed. In the train shed the tops of the rails are

* At the World's Columbian Exposition, in Chicago, the architectural plans for this passenger station have been placed on exhibition by the Prussian Minister of Public Works. Also a model of the large train shed is exhibited by the Union Company, of Dortmund.

about 4 m. (13.1 ft.) higher than the ground in front of the station itself. A prominent dome indicates to the passenger the door to the entrance hall. The dimensions of this, 41 by 18 m. (134 by 59 ft.), are such that, immediately on entering, the ticket offices are seen on both right and left. Moreover, on the right is a package-room, and on the left, rooms for the police and for the change of foreign money.

Directly beside the entrance hall to the left is the spacious baggage-room. The toilet-rooms for men and women lie between the entrance hall and the passage tunnel which leads under the tracks to Maximinen Street. The traveler passes half way through this tunnel, mounts a flight of steps and arrives at the waiting-rooms.

The waiting-room building contains on the main floor the waiting-room for first and second class passengers, and that for third and fourth class passengers; a dining-room situated between them; two ladies' rooms with a lavatory; rooms for royal passengers, and a few offices for employees (Plate III).

The kitchens and pantries for the restaurants are on an upper floor, while in the cellar underneath the waiting-rooms is space for storing provisions. On the main floor, beside the waiting-room of the first and second class passengers, is a buffet-room connected by a lift with the kitchen above. The cellar underneath the waiting-rooms is connected with Maximinen Street by a special tunnel.

For the passengers arriving from the west side of the Rhine a special exit tunnel has been provided underneath the tracks. At the end of this tunnel the traveler comes on the left to the baggage-room, and on the right to the package-room, toilets and lavatories. Moreover, near the baggage office are found some rooms for railroad officials, as also a hospital room for the reception of sick or wounded persons. In this northwest wing are found on the same level as the platforms two waiting-rooms for arriving passengers. The story above is reserved for the servants of the restaurant keeper.

For through passengers there are also two larger toilet-rooms at the end of the siding for the lines on the east of the Rhine.

At the extreme eastern end of the platforms, in the reception building, are the rooms for royal personages. The vestibule, which lies somewhat lower, is accessible by a few steps leading from the street. Between the rooms for royalty and the entrance hall rises the clock tower.

The baggage is carried from the baggage-room by means of barrows through special tunnels parallel to those used by passengers, and raised by hydraulic lifts to the baggage platforms. All these tunnels lead through to Maximinen Street; they are arched passages beneath the tracks, which later will in part be rented, but which will continue to be used by the ticket and baggage service until the reception building is completed. In these tunnels are also placed the dynamos for the electric lighting and the pumps for the hydraulic accumulators. The boiler house for these machines is located in Maximinen Street.

The front of the reception building is entirely constructed of Silesian sandstone.

All the roof structures of large span are built of iron. The ceilings of the entrance hall, baggage-room and exit hall are also supported by iron girders of different depths. These form rectangular panels which are filled with corrugated iron. The corrugations being in different directions in different panels, and the plates being partly arched, a striking ceiling pattern is formed.

The waiting-room building is built of iron-work with glazed brick and terra-cotta intermingled. In architectural comportment the rear of the reception building is also ornamented with glazed brick, while the roof is likewise of iron.

All floors are solidly formed by iron girders with béton arches turned between them.

The rooms of the entrance building and of the waiting building are heated by low-pressure steam; the boilers for this purpose are in an arched room underneath the tracks in Maximinen Street. In great part, however, the exhaust steam of the plant which drives the dynamos and pumps is utilized for heating.

(*b*) *Tracks and the Movement of Trains* (Plate III).—On each side of the long waiting building lie two main tracks, between which is an isolated platform 55 m. (180 ft.) in breadth. Two other pair of tracks terminate in this platform from each end, thus forming three projecting platforms. Further, there exist on both Maximinen Street and on the front means of exit. This arrangement was advantageous for Cologne, because nearly all trains are there made up. Each track has one platform for the passengers and another for the baggage and express. The tracks are spaced apart from 8.5 to 9.5 m. (27.8 to 31.1 ft.) when a baggage platform lies between, and about 12 m. (39.3 ft.)

when a passenger platform lies between. All the tracks are covered by a train shed.

The outside tracks, whose platforms are not directly connected with the middle one, are for freight trains, and for those local trains which are not used by passengers going far from the city. The switching connections are so arranged that each track can be used both for incoming and outgoing trains in many directions.

On both sides of the station are signal offices from which the signals and switches are operated. Each track has a signal for both outgoing and incoming trains, and the same is true for each of the main lines. Each signal office is under the charge of an official who has control of the departure and entrance of the trains. The two signal offices are nevertheless so far interdependent that the signals for the through trains on the main track can only be given by the common consent of both.

For the mails there is a special passage between the exit tunnels and Eigelstein Street which is connected with each baggage platform by a hydraulic lift. This tunnel passes under Marzellen Street and terminates at the main post office, so that the mail and express matter to and from Cologne is easily handled.

After the passengers and the mail for Cologne have been unloaded, the empty train, inclusive of postal and express cars, moves to the traffic station where the business of transferring through mail and express matter is done.

The lighting of the main passenger station is in general by electricity, but the offices are lighted by gas.

(c) *The Train Shed* (Plates VII, VIII and IX).—The train shed has a length of 255 m. (837 ft.) and a breadth of 92 m. (292 ft.), covering an area in round numbers of 22 200 sq. m. (238 970 sq. ft.). The following table gives a comparison with the other large train sheds of Europe:

Train Shed of Station.	Length. Feet.	Breadth. Feet.	Height. Feet.	Area covered. Square feet.
Frankfort-on-the-Main (3 train sheds)...	600	184	93	336 340
Cologne.....	837	292	79	238 970
Bremen.....	430	194	89	83 620
Anhalt in Berlin.....	550	199	112	109 630
Midland, Manchester.....	563	210	....	118 210
Union, Glasgow.....	520	198	90	103 080
St. Pancras, London.....	705	243	100	171 260
Cannon Street, London.....	656	190	108	124 870

The cross-section of the train shed is formed by three spans, a middle span of 63.9 m. (209 ft.) and two side spans of 13.4 m. (44 ft.). The height of the middle part is 24 m. (79 ft.); this was made especially low on account of the proximity of the cathedral. The trusses of the central span are formed by arched girders in pairs, the two in each pair being 0.8 m. (2.5 ft.) apart, and united by both horizontal and diagonal braces. The ends of the arches are hinged on pins, and are supported on a narrow horizontal bedplate which is restrained from moving in a horizontal direction.

The single trusses are for the greatest part of their length built as lattice girders, but from the ends to a height of 2 m. (6.5 ft.) they have solid webs. The flanges have a T section, and to these the double diagonals are directly riveted. Upper and lower flanges are symmetrical. The distance apart of the trusses is 8.5 m. (27 ft.) from center to center. The roof covering is supported by iron purlins of a I or Z section, which rest on the upper flanges of the trusses. The connecting joints are so arranged that they transmit only vertical forces, the purlins being able to change in length under changes of temperature. This is effected by having at every other panel where the wind bracing is connected a continuous purlin with projecting ends to which the intermediate shorter purlins are joined by rivets in oval holes.

The wind bracing consists of round steel rods which carry the wind pressure on any truss to the masonry abutments.

The trusses support a spandrel structure on each side, the walls of which, 7 m. above the side spans, are glazed throughout their entire extent. To light the train shed more completely an upper construction 35 m. (115 ft.) wide extends over the whole length with the exception of the two end panels. This upper construction is formed by single small saddle roofs which extend at right angles to the length of the shed, and by a series of longitudinal window lights along the ridge. The side surfaces formed in raising these above the ridge form a ventilating *louvre*. For the same reason the covering above the trusses is slightly raised above the rest of the roof, so that side openings are formed where smoke and dust may have exit. In total, the openings for ventilation have an area of 1 600 sq. m. (17 200 ft.).

The ends of the train shed are enclosed by framing attached to the end trusses and have ornamented windows. The wind pressure acting upon these ends is transferred downward to a special girder.

The end trusses have a breadth of 4.1 m. (13.4 ft.), the others being only 0.8 m. (2.5 ft.). The end truss and the two trusses next to it are at both ends of the train shed, connected together by continuous purlins and by diagonal members, thus forming a rigid system, which is firmly connected for a length of 21 m. (68.8 ft.) to the end abutments, but which is allowed motion on the other four abutments under expansion from temperature.

The trusses of the side spans consist of arched girders, the lower chord of which is so elevated that the pressure line in the upper chord under uniformly distributed load has the same circular form as the chord itself. Against unsymmetrical loads these arches have a moment of resistance amply sufficient.

The roof covering is supported by Z beams. On the crown of each side span there is a longitudinal *louvre* which serves both for lighting and for ventilation. All the roof covering is corrugated iron.

The glass of the roof-lights has a thickness of 6 mm. (0.24 in.). The glass plates extend the entire width of the opening, the edges lying upon galvanized iron gutter plates, and are connected by screws passing through __⌒__ springs between them. In order to avoid stresses in the glass, pieces of felt are placed between it and the springs, and the felt is protected from dampness by being wrapped in tinfoil.

At each end of these upper windows in the direction of the length of the train shed is placed a ladder which, on one side of the building, is connected with steps leading downward.

The erection of the train shed was done under difficulties, since the work had to be carried on without disturbing the movement of trains and passengers on the tracks and platforms below. For an erection staging an iron structure 38.85 m. (127 ft.) in span was provided which had three trusses 5.5 m. (18 ft.) apart; these were firmly united by diagonal and lateral bracing. This staging was supported by 11 pair of wheels on a track on each side, so that it could easily be moved in the direction of the length of the building as the work advanced. The staging was so managed that it did not in any way hinder the temporary structures or the erection of the waiting-room building.

The movement of the staging, whose weight was about 140 tons, was effected very simply by 16 laborers with crowbars on each side, the time required to move it from one truss to the next, a distance of 8.5 m. (27 ft.), being from 45 to 60 minutes.

The total weight of the iron-work of the train shed, exclusive of corrugated iron, is about 3 130 tons (6 900 500 lbs.). This amounts to 160 kg. per square meter (32.8 lbs. per square foot) of floor area for the large span, and 90 kg. per square meter (18.40 lbs. per square foot) for the side spans, the latter including the iron-work of the side wall on Maximinen Street.

IV. The Passenger Stations at West Cologne and South Cologne.

The passenger stations at West Cologne and South Cologne, which lie on the main line to Bingen, are arranged in a similar way.

The station at West Cologne receives its traffic from that part of the city, at present not thickly populated, and from the large village Ehrenfeld.

The station at South Cologne replaces the old station Pantaleon, and already has a considerable business, since its location is favorable for the southern part of the city.

The streets adjacent to these stations have their surfaces about 5 m. (16.4 ft.) lower than the tracks. The passengers pass from the front of the station into the entrance hall on the same level, in which are found the ticket office, baggage-room and toilet arrangements. A flight of steps, 3 m. (9.8 ft.) in width, leads to the platform between the main tracks, which, for a distance of 400 m. (1 312 ft.), are spread 14 m. (46 ft.) apart for this purpose. At the south end of this platform is a small waiting-house, and at the other end of the train shed is a narrow office for the station-men. This platform and the tracks are covered by an arched train shed of 19.5 m. (63 ft.) span and 60 m. (197 ft.) length, the sides of which are formed of iron columns walled in between with brick.

V. The Traffic Station.

The traffic station lies at the junction of the lines to Aix-la-Chapelle and Bingen. Its principal use is for storing empty cars, and it is connected with the main station by two tracks. Besides the tracks for empty cars, the traffic station includes the following:

First.—A car shed for cleaning the empty cars.

Second.—A shed for free and customs fast freight.

Third.—The place for transferring the through mails.

Fourth.—A round-house for passenger locomotives.

The car shed is about 125 m. (410 ft.) long, and has four tracks placed 4.7 m. (15.4 ft.) apart upon which cars are stored and cleaned. The walls are formed of iron bracings.

The freight shed has one part for free and another for customs freight. That for the free, or non-dutiable, freight has unloading scaffolds shaped like saw teeth in plan, so that on each diagonal face three cars can be handled. In front of the shed are four such scaffolds or platforms; moreover, in the rear of the shed are several others roofed over. By this arrangement the cars by the side of any given scaffold can be easily and quickly taken away by a locomotive without disturbing the other cars in front of the shed. This arrangement has proved to be an excellent one. The shed itself is built of wood; all the saw-tooth-shaped scaffolds are covered by the projecting roof. The neighboring shed for fast freight matter is accessible by a turn-table. At the end of this structure is an office building for those who have the conduct of this business.

The ground around the freight shed is connected with the neighboring streets of the city by an approach having a grade of 1 in 30.

The location for the handling of the mails is connected with the traffic station by a bridge over the west-bound freight tracks. The arriving postal cars are run upon a track over this bridge from which they are brought to the special platforms where the mail matter is transferred into different cars for different directions.

The locomotive round-house has room for 36 locomotives, and is reached by two turn-tables. The rear semi-circular wall is of brick, while the front columns, the doors and the roof consist of iron. The supplies of coal for the passenger locomotives are brought by small coal cars (so-called "dogs") which are lifted up by a crane and dumped into the tender.

VI. The Freight and Switching Station Gereon.

(*a*) *The Freight Yards.*—The Station Gereon serves in part for the through and in part for the local traffic, but the former is by far the more extensive.

About 70 freight trains arrive and depart every day. Almost all arriving trains must be made up again, and hence much switching is necessary.

The main freight line, which departs toward the north and west

after traveling out from the south-bound line, divides the Station Gereon into two parts. This is not a good solution of the problem, but it was demanded by the local circumstances.

In consequence of this division of the freight station, it was thought best to use the tracks south of the main line for the trains toward Aix-la-Chapelle and for the local traffic, and those lying north of the main line for the trains toward the south and for the traffic on the right bank of the Rhine. Thus the trains when made up can move from their sidings without crossing the main tracks.

Moreover, on the north side of the main tracks there is another track for cars for South Cologne, the harbor and other local points.

The tracks for departing trains are laid opposite to the west station. For trains toward Bingen and Trier there are three tracks, and for those toward Aix-la-Chapelle and Deutz there are two tracks alongside the main line. Moreover, there is a special track provided for trains leaving for Deutz. In general, arriving freight trains use the same tracks as those leaving.

At the front end of the tracks for departing trains there is an elevation of 0.5 m. (1.64 ft.), which is reached by a 1% grade in 50 m. distance, the grade on the other side being 2 per cent. This elevation is necessary in order that the cars may be easily uncoupled. The cars are not pushed off with a shock, but the train is brought into uniform velocity, and the cars move off in a corresponding manner. The velocity with which a train can be thus broken up depends upon the intervals in which the cars are detached. This interval must be so large that two cars which have the furthest distance to run, and which are to be switched upon different sidings, may be sufficiently far apart at the end of that distance so that the last switch may be easily thrown between them.

But since loaded cars move faster than empty ones, and, on the other hand, many cars move slowly on account of some defect (insufficient oiling, wear of axles, etc.), attention must be given to this, and the velocity with which the cars are moved out must be regulated accordingly. In the construction of switching tracks of this kind the distance which two cars have to run before being switched upon their respective sidings should be as small as possible.

At the Station Gereon it is possible during 24 hours to run out about 4 000 cars from one of these gravity tracks. However, a few

horses are always used to assist in accelerating the movement of the slowest cars, although the grades in general are very well arranged. The summit of these grades lies 3.60 m. (11.8 ft.) higher than the ends of the tracks, as these are in the public loading street and the freight shed is on the level of the neighboring streets. This difference in elevation is, with the exception of the grade of 2% in 50 m. distance, overcome by a grade of 1 in 200 in the switching yards and curves, and by a grade of 1 in 500 through the rest of the station. In order to arrange the cars of a train in the order of the several stations, a number of short tracks are placed on each side of the yard.

The switches are mostly operated from elevated switch houses, one of which has as many as 15 levers. Such a number must be regarded in busy times as extraordinarily large for one man to attend. This switchman sees the number of the track written upon the bufler of the car, and thus knows which lever is to be turned. In order that switches which are far distant from the switch house shall not be reversed in case a car is upon the switch rails, special pressure rails are provided which prevent it. The cars are brought to a standstill by means of wheel skids, which are made very strong, since the wheel, held fast by the skid, often slides along on the rail a distance of 10 to 15 m. (33 to 49 ft.).

Besides the two main freight tracks and the tracks for sorting, there are also two tracks for the movement of locomotives. Between the locomotive tracks and the main tracks, on the northeast side of the station, is the siding for the cars which carry supplies about the station. The tracks for the locomotives are extended beneath the main line toward Bingen and under a part of the traffic station, terminating in a round-house, having room for 30 freight locomotives.

The arrangement of this round-house is similar to that at the traffic station. The locomotives are furnished with coal from the elevated coaling bins at the traffic station, the coal cars arriving at the traffic station being dumped into smaller coal cars standing on a level 1.5 m. (4.9 ft.) lower. These small coal cars, each containing a definite quantity of coal, are, by tipping, dumped directly into the tenders.

The locomotives are supplied with water from the city water works. However, in order that the supply may not fail in case of an accident to the city works, a tower has been built near the round-houses. This tower supports a reservoir, built according to the system of Professor

Intze, of Aix-la-Chapelle, which contains 600 cu. m., and which is placed at such a height that the locomotives of the high elevated passenger round-house can also be readily supplied with water. The reservoir has not been encased to protect it against frost, since there is no danger of freezing when in continual use.

A repair shop for the locomotives is situated near this round-house, but extensive repairs are made in one of the main shops of Cologne. For the smaller repairs of the cars a workshop is situated at the end of the switching tracks.

(*b*) *The Local Freight Business.*—All the freight in less than carload lots which arrives at the Station Gereon is unloaded, and this is done in the main freight shed.

In the year 1889 the local freight received at Gereon averaged 168 tons, and that shipped 184 tons, while 162 tons were transferred at the freight shed. From these numbers it is to be seen that arrangements had to be made, to accommodate many cars in the shed. For this purpose there was erected in front of the shed a system of turn-tables, which lead to the loading platforms. On each side of these platforms two cars can be handled simultaneously. The shed has a length of 200 m. (655 ft.) and a breadth of 40 m. (131 ft.). In total, 48 cars can be loaded or unloaded at the same time. The shed was made extraordinarily wide in order that freight which was to be unloaded in special places should not have to move too long distances. The shed has solid walls and a high roof, covered with a double thickness of roofing felt; it is lighted throughout along the ridge and also on each side by gable windows between each pair of trusses. Adjoining is the shed for customs freight, which is similarly constructed, and has room for loading and unloading 10 cars in a similar way.

Freight particularly liable to take fire is stored in a special shed in the neighborhood of Erft Street, which is built entirely of iron and corrugated metal.

To accommodate the public, a number of so-called loading streets are provided. The tracks on these are separated 14.5 m. (47.6 ft.) apart. In total, about 220 cars can be loaded or unloaded.

On Erft Street there are also cattle pens, but these are unimportant in comparison with those now being built by the city of Cologne.

The outdoor lighting of the Station Gereon is for the most part by electric lights, while the offices and sheds are lighted by gas. Since

the principal work of making up trains is done at night, care has been taken to provide sufficient light.

VII. The Freight Station, South Cologne.

The freight station at South Cologne is served by a special track from the Station Gereon, but a connection with the main track is wanting. For this reason small articles of freight are not sent directly to South Cologne, although such are received in the freight shed there. The principal business at this station consists in unloading carloads of freight. On the loading streets there are tracks on both sides, 14 m. (46 ft.) apart, so that 160 cars can be loaded and unloaded at the same time. The station is connected with the neighboring streets, whose surfaces are 4 m. (13 ft.) deeper, by approaches having grades of 1 in 30.

VIII. The Street-Crossings.

The iron structures of the street-crossings are partly of arched trusses and partly of plate girders. With the plate girders continuous spans are avoided. Girders with projecting ends, which support a central span, are preferred. The joints where the independent span rests upon the projecting end are so constructed that only very slight bending moments can be transferred. In the computation of the arched trusses they are regarded as having hinges at the crown and at the springing lines, but the hinge is not actually inserted at the crown, although it has been the aim to arrange the connection and the splice plate so that a hinge action may exist. To secure a thick floor, buckle plates were used. In the middle of the buckle plates is a hole, by which the drainage is led to a gutter. The buckle plates are covered by a layer of gravel about 0.3 m. (1 ft.) thick, and upon this the iron crossties which support the rails are laid.

In order to secure good light, the masonry walls are mostly faced with white porcelain tiles.

The span of the structure across main streets is 20 m. (65.5 ft.), while for less important streets it is 15 m. (49 ft.).

IX. Construction.

As already mentioned, the general plan for the reconstruction of the railroads in Cologne was in 1883 so far developed that in that year the Prussian House of Deputies appropriated the sum of 24 500 000

marks ($5 900 000) for its execution. After the greater part of the real estate had been purchased, in 1885, construction was begun on that part of the work which was not connected with the old tracks and stations. In particular this included that part of the roadbed and the street-crossings along by the new ramparts. At the same time the tracks in the old part of the city were so moved that half of the elevated structure for the new tracks could be built. In this way it was possible, by the use of several temporary tracks, to bring into service two elevated tracks. First, the trains for the right bank of the Rhine and those for Aix-la-Chapelle and Crefeld were brought upon these tracks, while those for the lines to Coblenz and Trier continued to run on the old roadbed. After a short time it was possible to bring these, also, upon the new elevated tracks and into the new station The entire ticket and baggage business was transferred temporarily to rooms under the elevated structure on Maximinen Street; waiting-rooms and offices for trainmen were temporarily put up, so that the old reception building could be torn down and the erection of the new one be carried on. The corner-stone of the new reception building was laid May 7th, 1892.

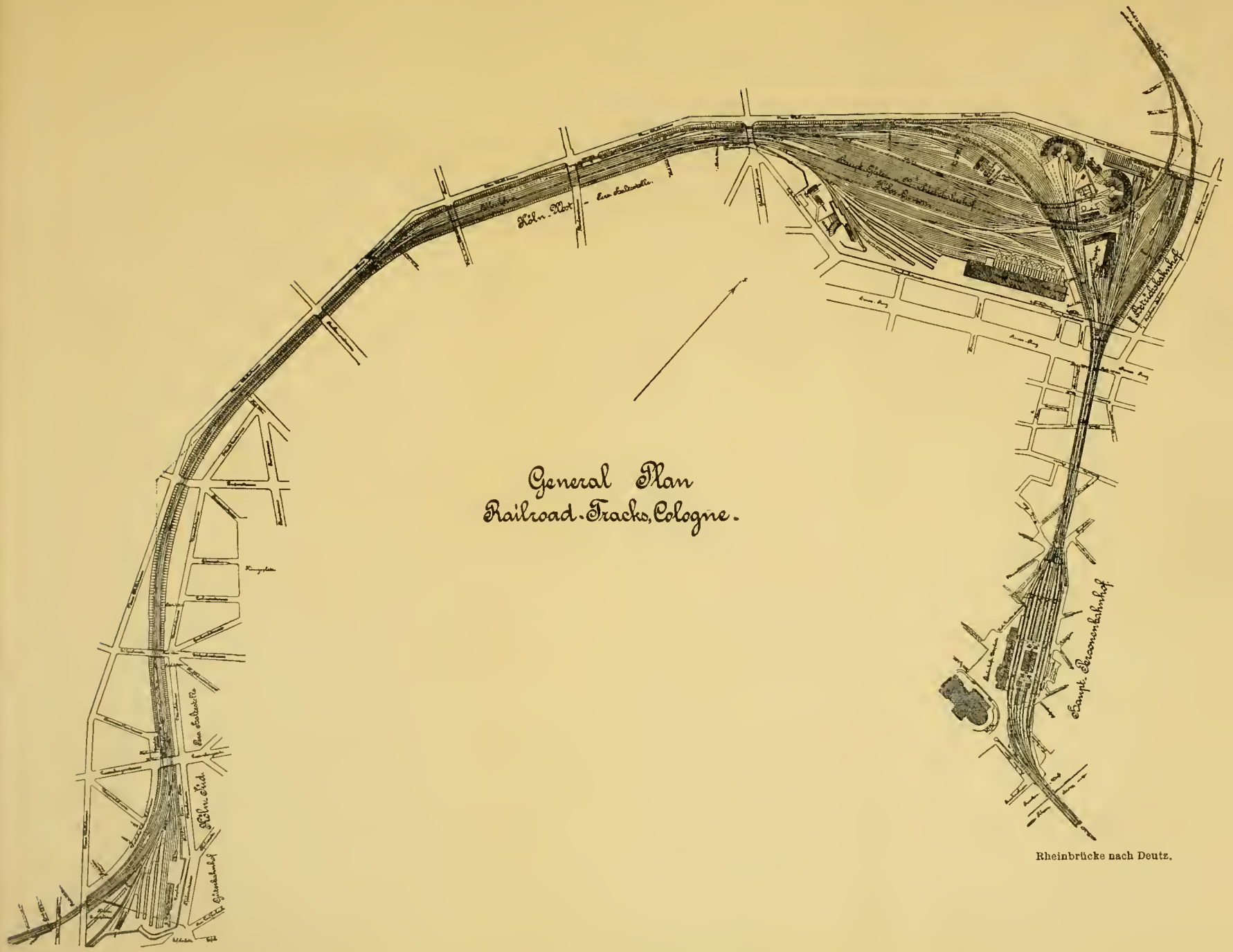
Meanwhile the new Station Gereon was built by additions to the old building, and brought into service; but the traffic and the small freight still remained at the old station. In this manner every foot of ground which was taken from the old system had been previously replaced by the new system, so that the entire construction was carried on step by step and in systematic order.

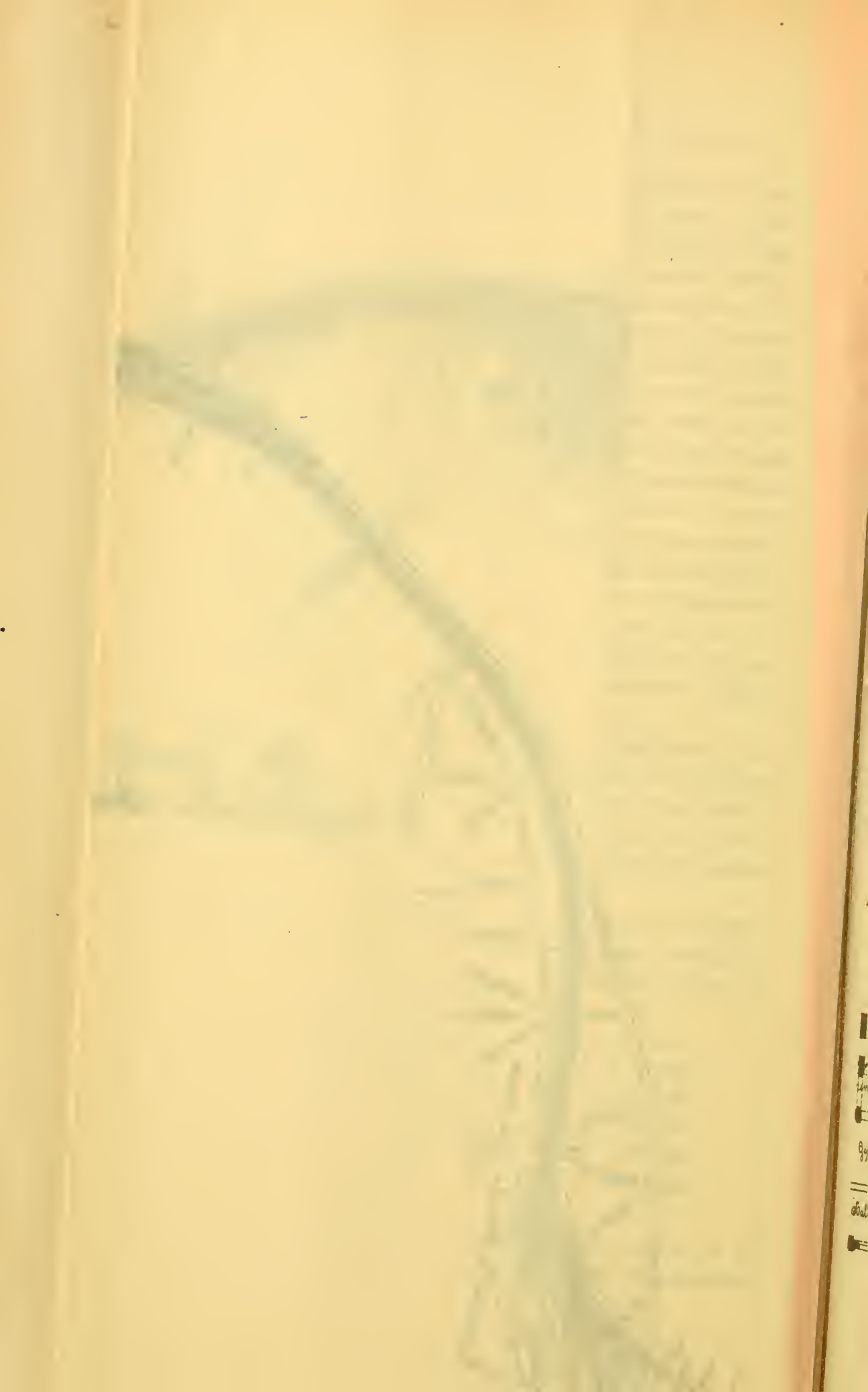
In the year 1892 there was appropriated 7 400 000 marks ($1 700 000) additional, for extensions unforeseen in the original plans, so that the entire probable cost is 31 900 000 marks (about $7 600 000), divided as follows:

	Marks.
Real estate	11 000 000
Earthwork and elevated tracks	2 000 000
Bridges and street-crossings	4 500 000
Buildings	10 000 000
Superintendence	1 000 000

and so forth.

At present the construction is so far advanced that the completion of the entire work may be reasonably expected by the close of the year 1894.


General Plan
Railroad-Tracks, Cologne.
Rheinbrücke nach Deutz.



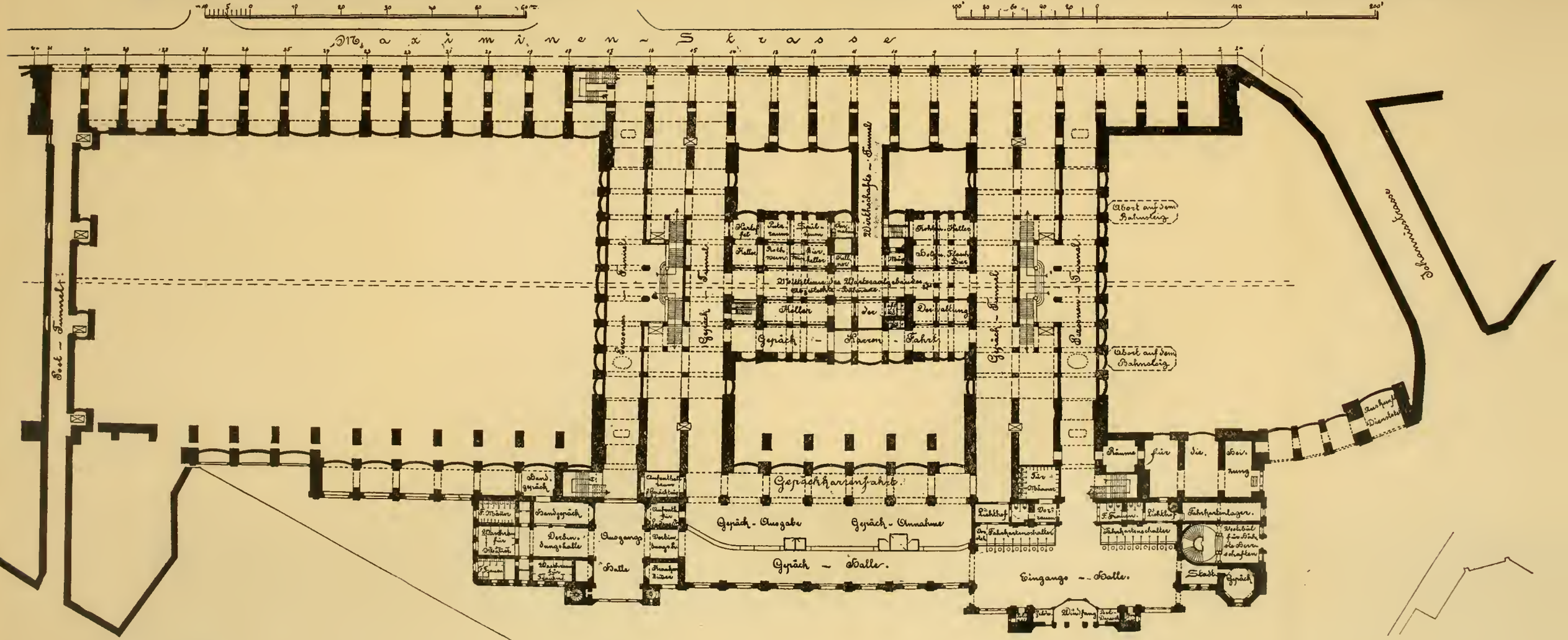
VOL. XXIX, No. 611.
TRANS. AM. SOC. CIV. ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE II.

Hauptbahnhof Köln.

Grundriss des Erdgeschosses bezw. Unterbau.

Central-Depot, Cologne.

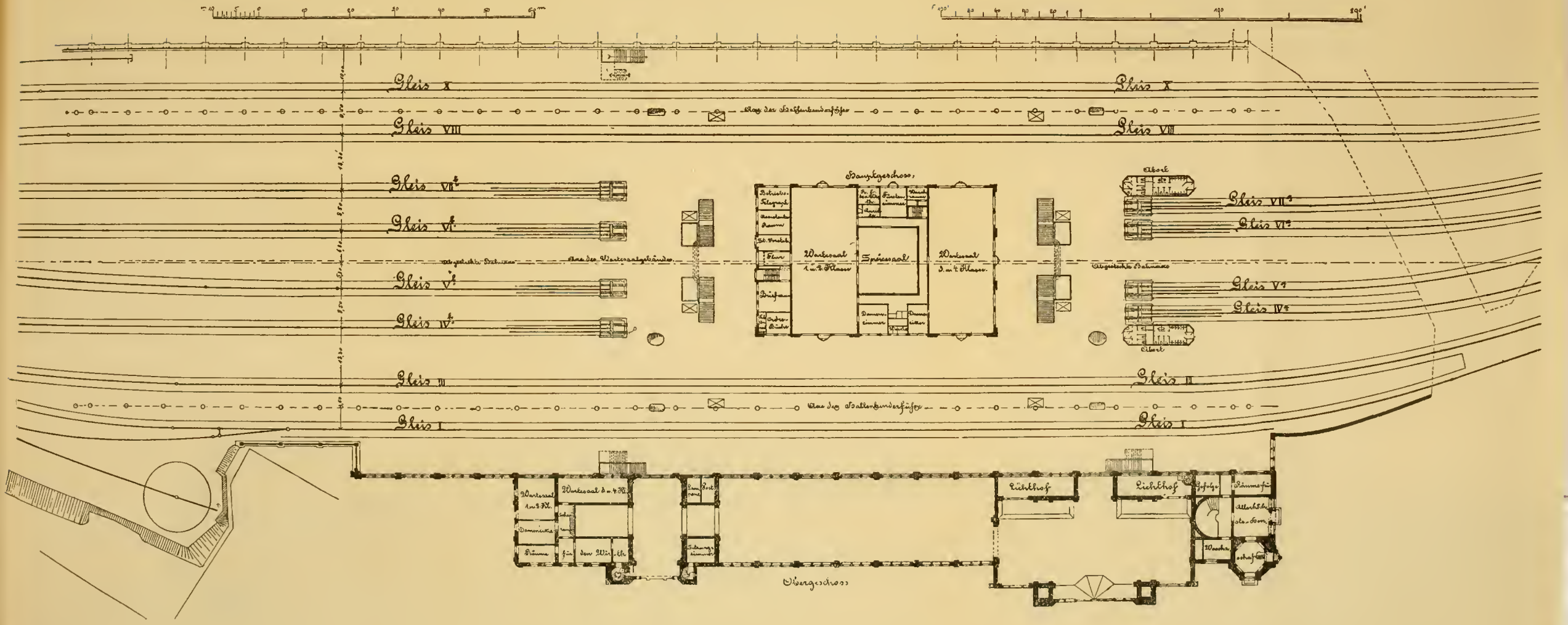
Plan of the ground-floor resp. of the subconstructions.



VOL. XXIX, No. 611.
TRANS. AM. SOC. CIV ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE III.

Hauptbahnhof Köln.
Grundriss in Höhe des Bahnsteigs.

Central-Depot Cologne.
Plan in the level of platform.



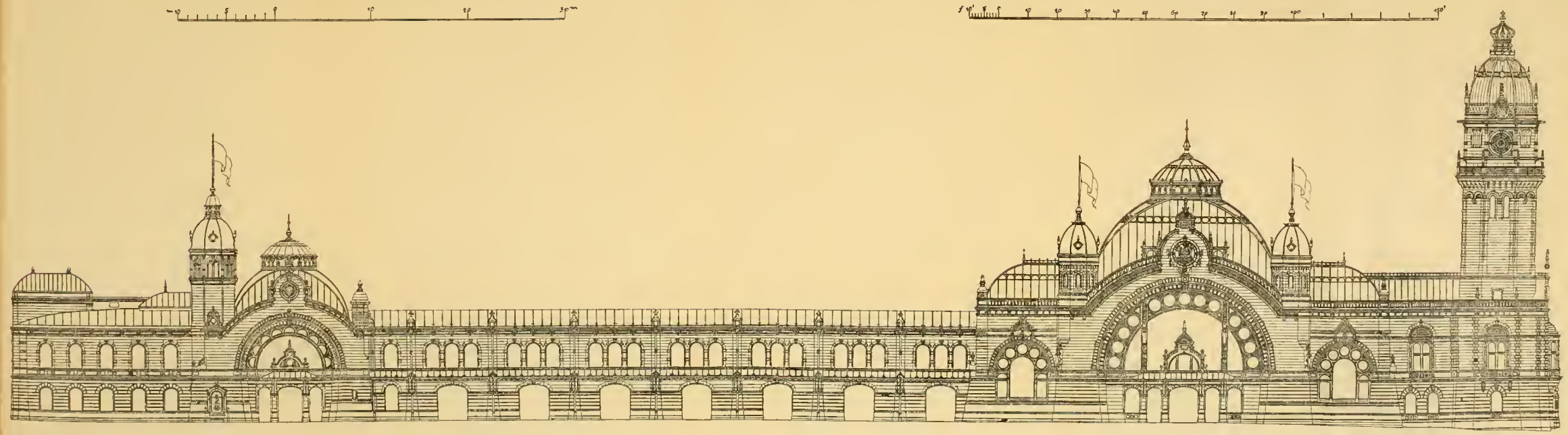
VOL. XXIX, No 611.
TRANS. AM. SOC. CIV. ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE IV.

Vordergebäude des Hauptbahnhofes Köln.

West-Ansicht.

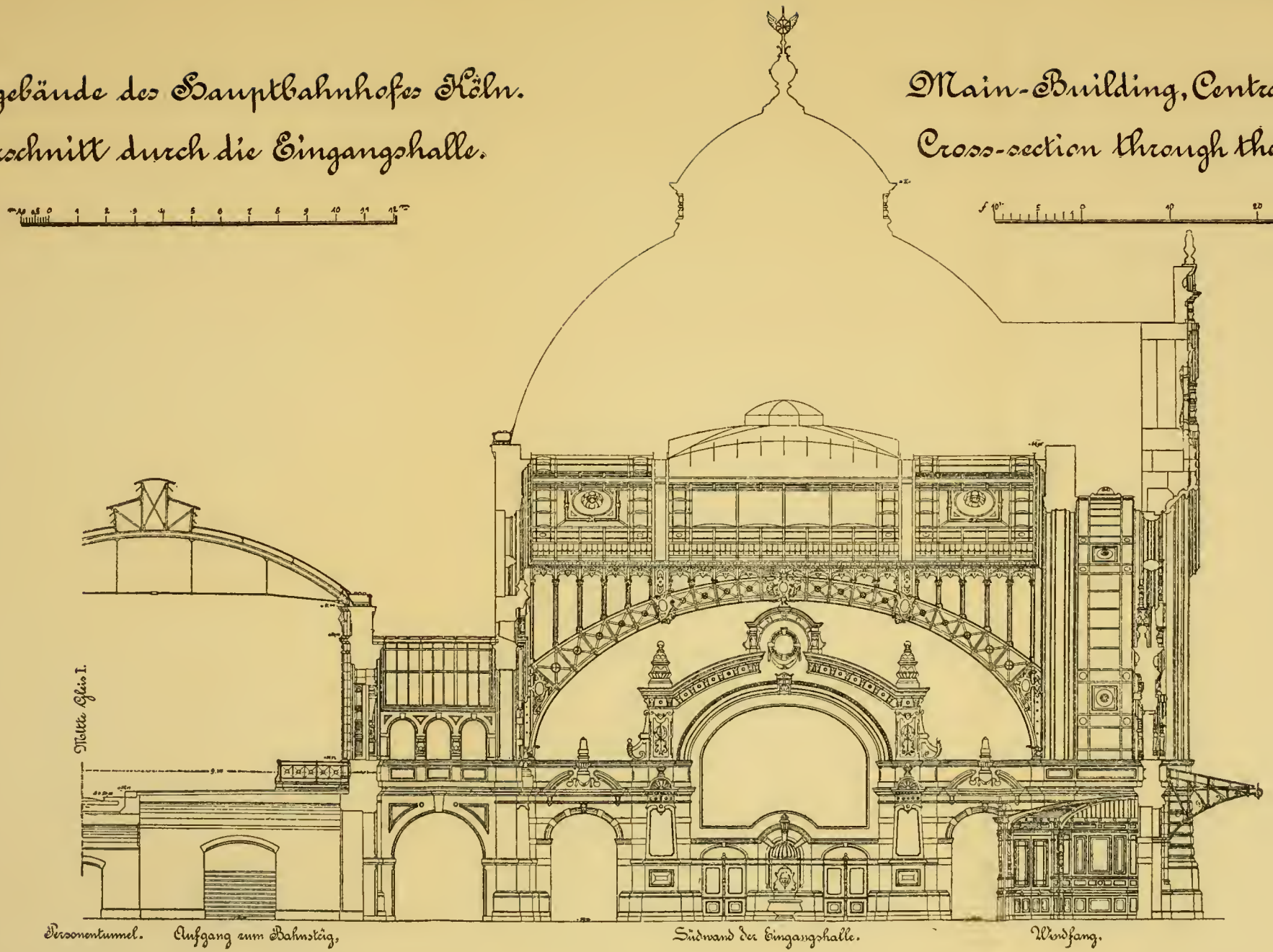
Main-Building, Central-Depot Cologne.

Elevation, West.



Vordergebäude des Hauptbahnhofes Köln.
Querschnitt durch die Eingangshalle.

Main-Building, Central-Depot Cologne.
Cross-section through the entrance-hall.



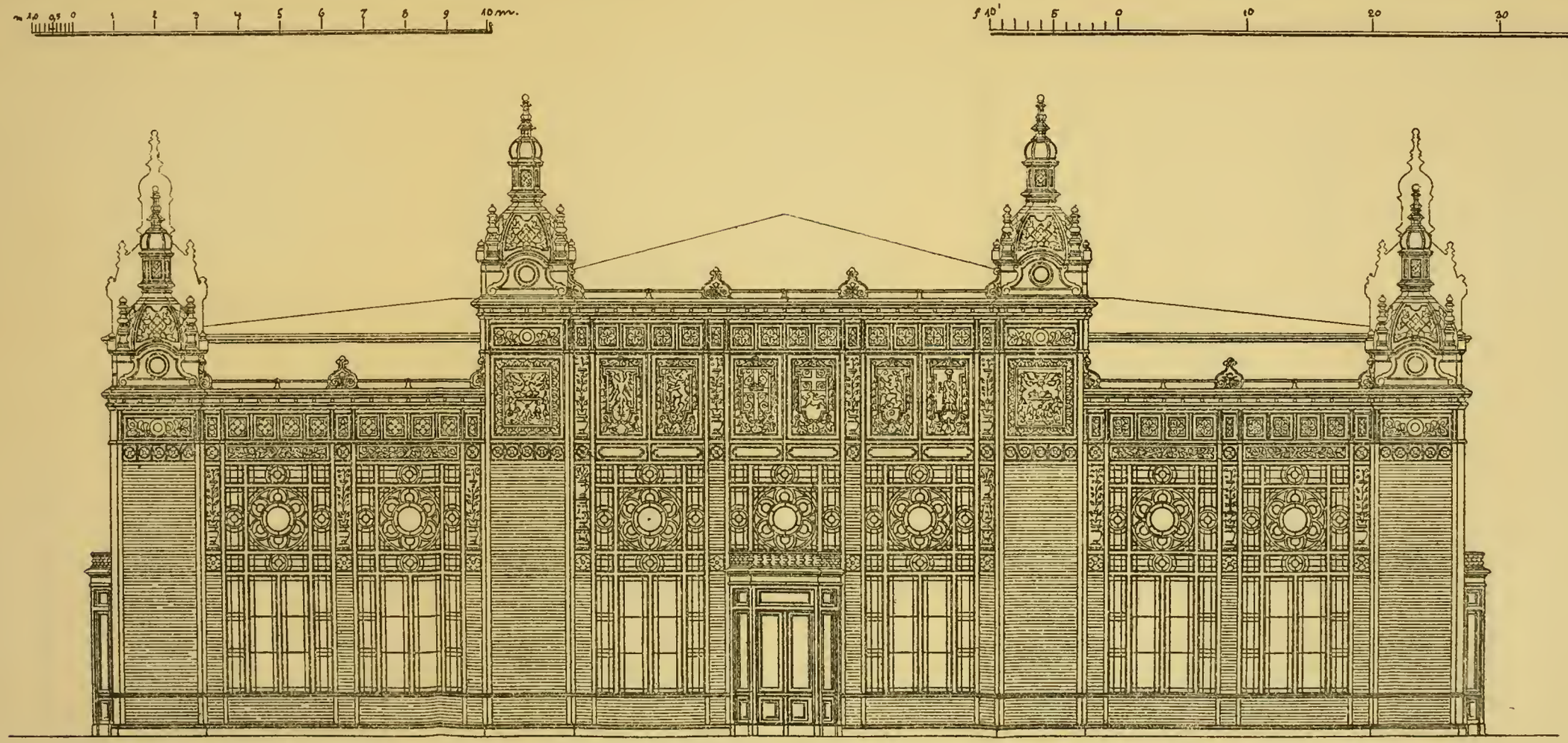
VOL. XXIX, No. 611.
TRANS. AM. SOC. CIV. ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE VI.

Hauptbahnhof Köln.

Vorderansicht des Wartesaalgebäudes.

Central-Depot Cologne.

Front-elevation of the waitingroom-building.



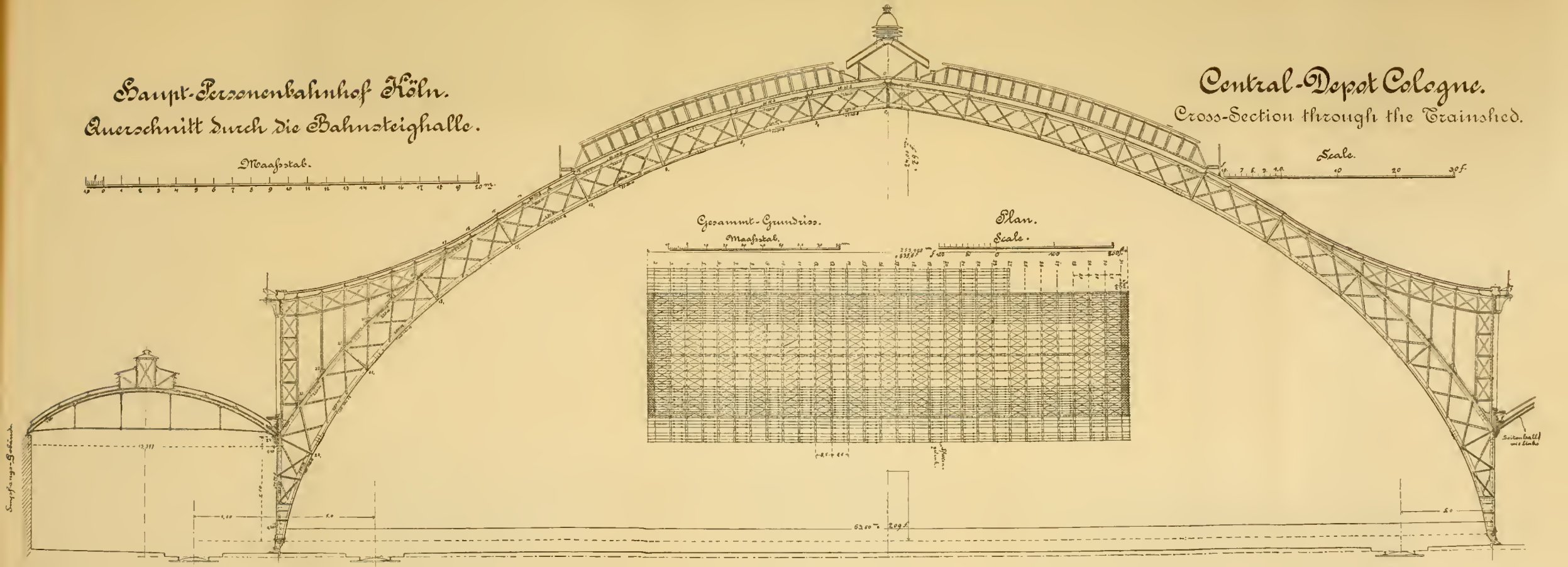
VOL. XXIX, No. 611.
TRANS. AM. SOC. CIV. ENGRS.
LOHSE ON RAILROAD TRACKS AND STATIONS IN COLOGNE.
PLATE VII.

Haupt-Personenbahnhof Köln.

Querschnitt durch die Bahnsteighalle.

Central-Depot Cologne.

Cross-Section through the Trainshed.



Haupt Personenbahnhof Köln.

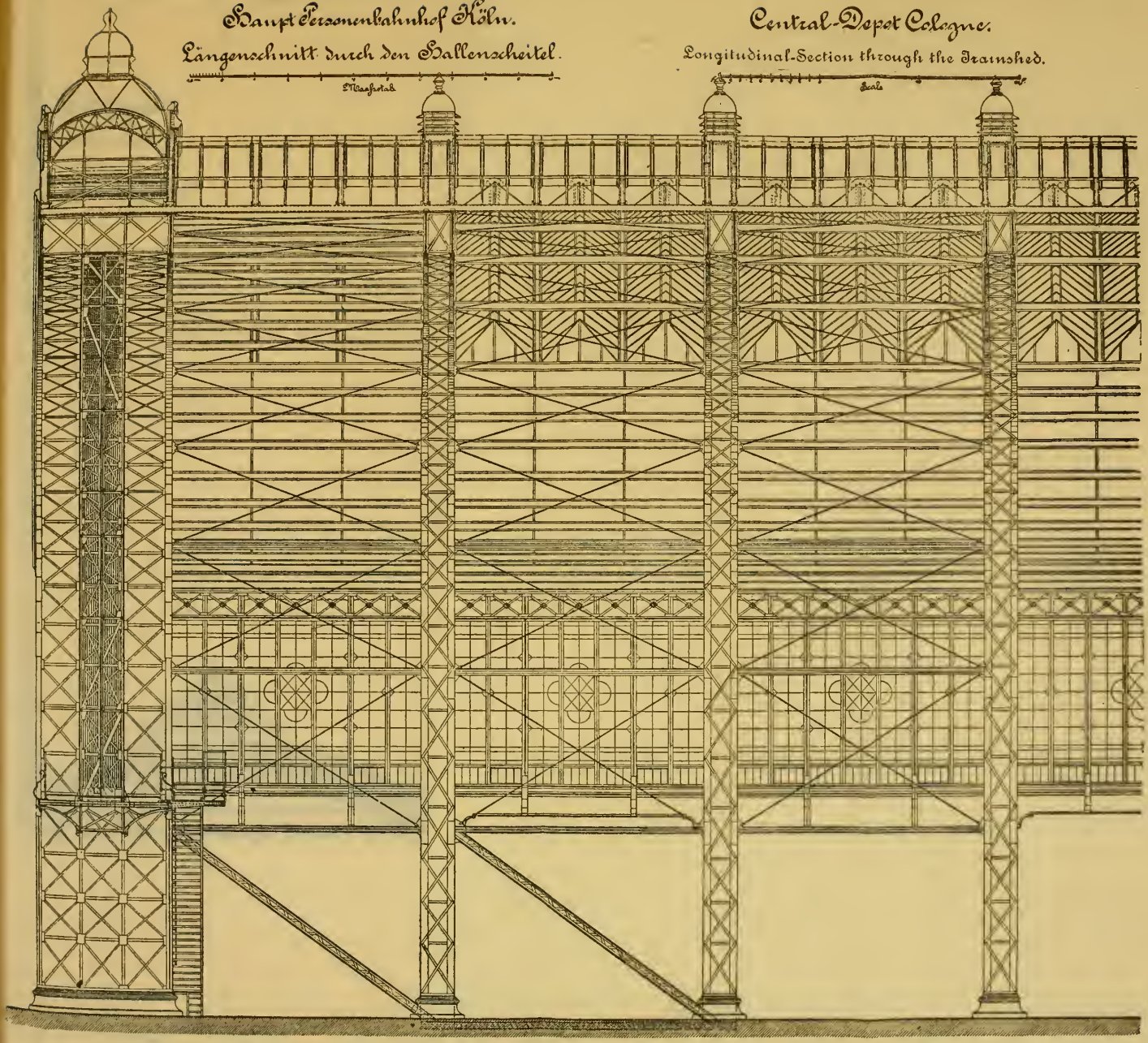
Längenschnitt durch den Hallenscheitel.

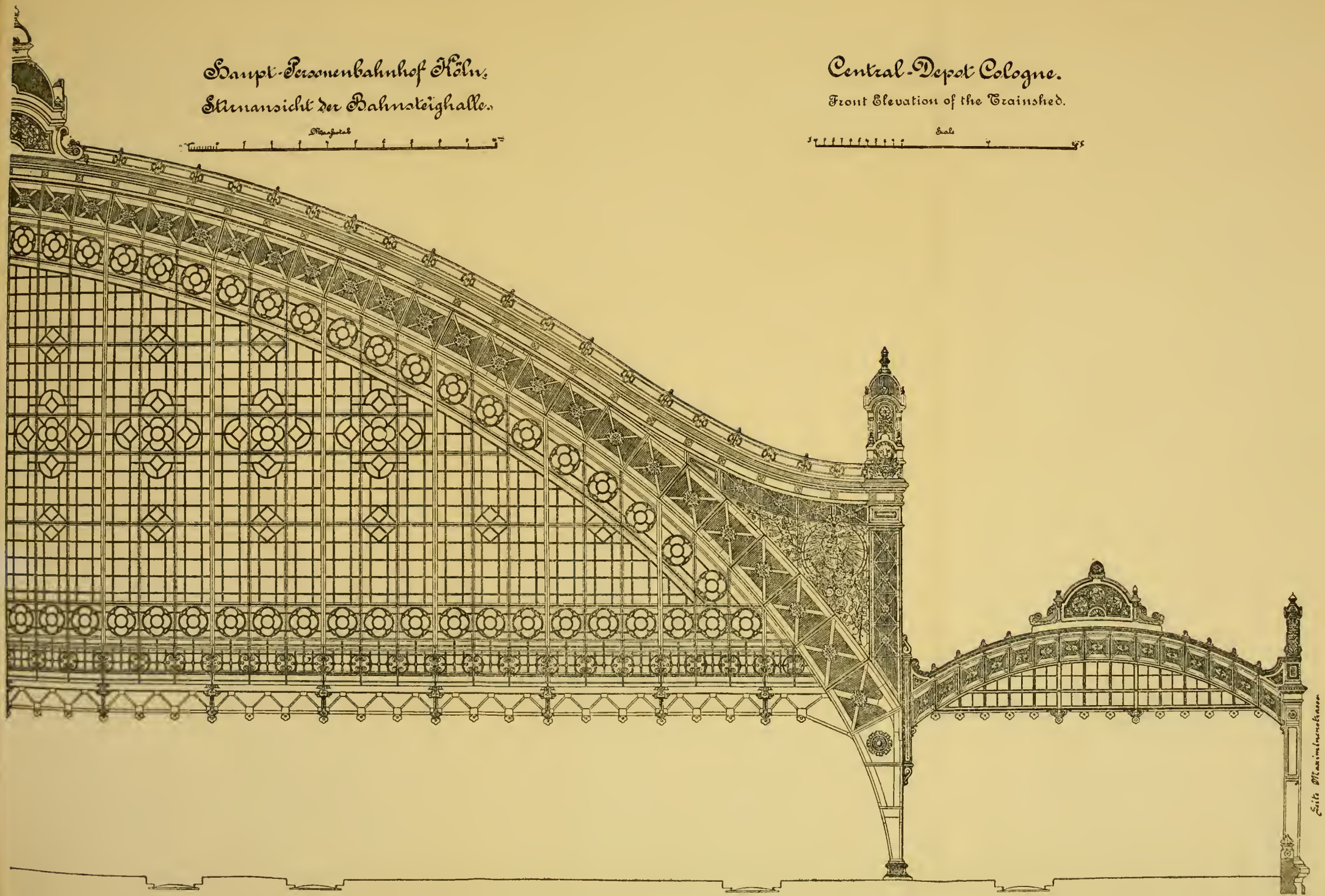
1 Maßstab

Central-Depot Cologne.

Longitudinal-Section through the Trainshed.

Scale




Haupt-Personenbahnhof Köln.
Stirnansicht der Bahnsteighalle.
Central-Depot Cologne.
Front Elevation of the Trainshed.
Scale

The execution of the plans and the construction of the new system was first done by the Royal Railroad Board of Cologne (left bank of Rhine), under thedirection of Ober-Bau und Geheimer Regierungs-rath Dircksen, so long as the work made but few encroachments upon the old system. But as continual changes in the movement of trains were demanded, in order to facilitate the construction, the further development of the plans and the conduct of the work was transferred to the Traffic Office Cologne-Düren, the General Manager of which is Regierungs und Baurath Blanck. At present Regierungs und Baurath Wessel has the direction of the work, while the Bureau of Architecture is in charge of Bau-Inspector Weithmann, and that of Engineering Construction in charge of Bau und Betriebs-Inspector Lohse. Among different engineers who have been engaged on designs and construction should be especially mentioned the Division Engineers Kiel and Baltzer.

The plans for the reception building of the main passenger station were made by Professor Frentzen, of Aix-la-Chapelle, while those of the waiting-room building and the train shed are due to Professor Jacobsthal, of Berlin. The latter has also been employed on many other problems of an architectural kind.

Explanation of the More Important German Words on the Plates

Plate I.

Haupt-Personenbahnhof.....Main Passenger Station.
Dom.....Cathedral.
Rheinbrücke .....Rhine Bridge.
Betriebsbahnhof.....Traffic Station (auxiliary yard to Passenger Station.
Haupt, Güter und Verschiebe-
bahnhof .....Main Freight and Switching Station.
Personen Haltestelle.....Local Passenger Station.

Plate II.

Eingangs-Halle.....Entrance Hall.
Fahrkarten-Schatter.....Ticket Office.
Gepäck-Halle .....Baggage Hall.
Gepäck-Annahme.....Outward Baggage Office.
Gepäck-Ausgabe.....Inward Baggage Office.
Ausgangs-Halle .....Exit Hall.

Plate III.

Wartesaal	Waiting-Room.
Speisesaal	Dining-Room.
Damenzimmer	Ladies' Room.
Fürstenzimmer	Royal Waiting-Room.
Stations-Vorsteher	Station Master.
Abort	Toilet-Rooms.
Lichtho	Light Well.
Obergeschoss	Upper Story.
Gleis	Track.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

612.

(Vol. XXIX.—August, 1893.)

THE REARRANGEMENT OF THE RAILWAY TERMINAL SYSTEM AT ALTONA, WITH SPECIAL REFERENCE TO THE AVOIDANCE OF GRADE CROSSINGS.

By R. CAESAR, Regierungs und Baurath, Member of the Royal Board of Railroad Directors at Altona, Prussia.

Translated from the German by WM. H. SEARLES, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The two cities of Hamburg and Altona, which unitedly have about 750 000 inhabitants, are built up so nearly together that it is impossible to tell where one city ends and the other begins (Plate II, Fig. *C*). From a commercial standpoint they are therefore to be regarded as one city.

In the plans for the reconstruction of the railway terminal system and the line connecting the two cities, which no longer met the requirements of the times, it was determined to take the trains entering Hamburg from the directions of Lübeck, Berlin, Hanover, Bremen and Cuxhafen further on over the four tracks of the Connecting Railway, and let them stop at the Altona Terminal. In this manner it became

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

possible to distribute the passengers at the various depots of the Connecting Railway, to discharge them as near as possible to their dwellings, and to relieve the main station of a portion of the traffic. On the other hand, trains coming from the north, that is, from Glückstadt, Flensburg and Kiel, and running into the Altona Depot, will be carried for the very same reason over the Connecting Railway to the main station of Hamburg. All through trains, as well as the suburban trains from the above-mentioned lines, are to use, on the Connecting Railway, the two south tracks, while the two other tracks serve exclusively for the city traffic, and for the Blankenese traffic therewith connected.

The depot of Altona is therefore:

1. In regard to through traffic—
   - *a.* The terminal depot for the lines entering from the direction of Hamburg.
   - *b.* A through station for the northern traffic.
2. Regarding the city traffic it is—
   - *a.* Terminal station for the purely city trains.
   - *b.* A through station for the trains running between Blankenese (a suburb) and Hamburg.

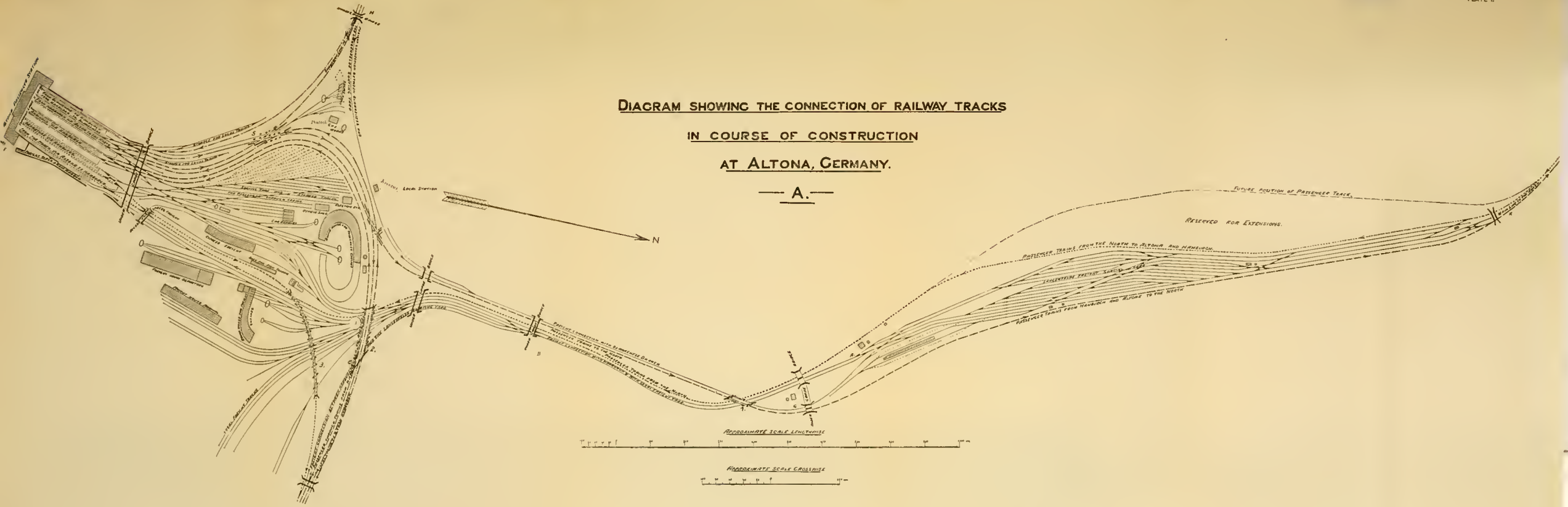
Since the main station at Altona, for local reasons, had to remain a head, or pocket, station, there resulted, through the chosen arrangement and the before-mentioned conditions of trade, a large number of grade crossings of tracks. These were considerably increased by the fact that on the northern tracks, outside of the passenger depot of Altona, a switchyard had to be established, at which all the freight trains of the various lines terminate and begin their course; and that from the same, therefore, there had to be established the following independent connections (Plate I):

- *a.* In the direction of Hamburg with the through tracks of the Connecting Railway, which, at the same time, serve as freight train tracks (*A*, *B*, *C*, on Plate I).
- *b.* In the direction of Altona and its harbor, with the local station of Altona and the harbor tracks (*A*, *B*, *E*, *F*, on the plate).
- *c.* In the direction of Blankenese with the Blankenese passenger train tracks (*G*, *H*, on the plate).
- *d.* In the northerly direction with the main tracks of the northern line (*I*, *K*, on the plate).

VOL. XXIX, No. 612.
TRANS. AM. SOC. CIV. ENGRS.
CAESAR ON RAILWAY TERMINAL AT ALTONA.
PLATE I.

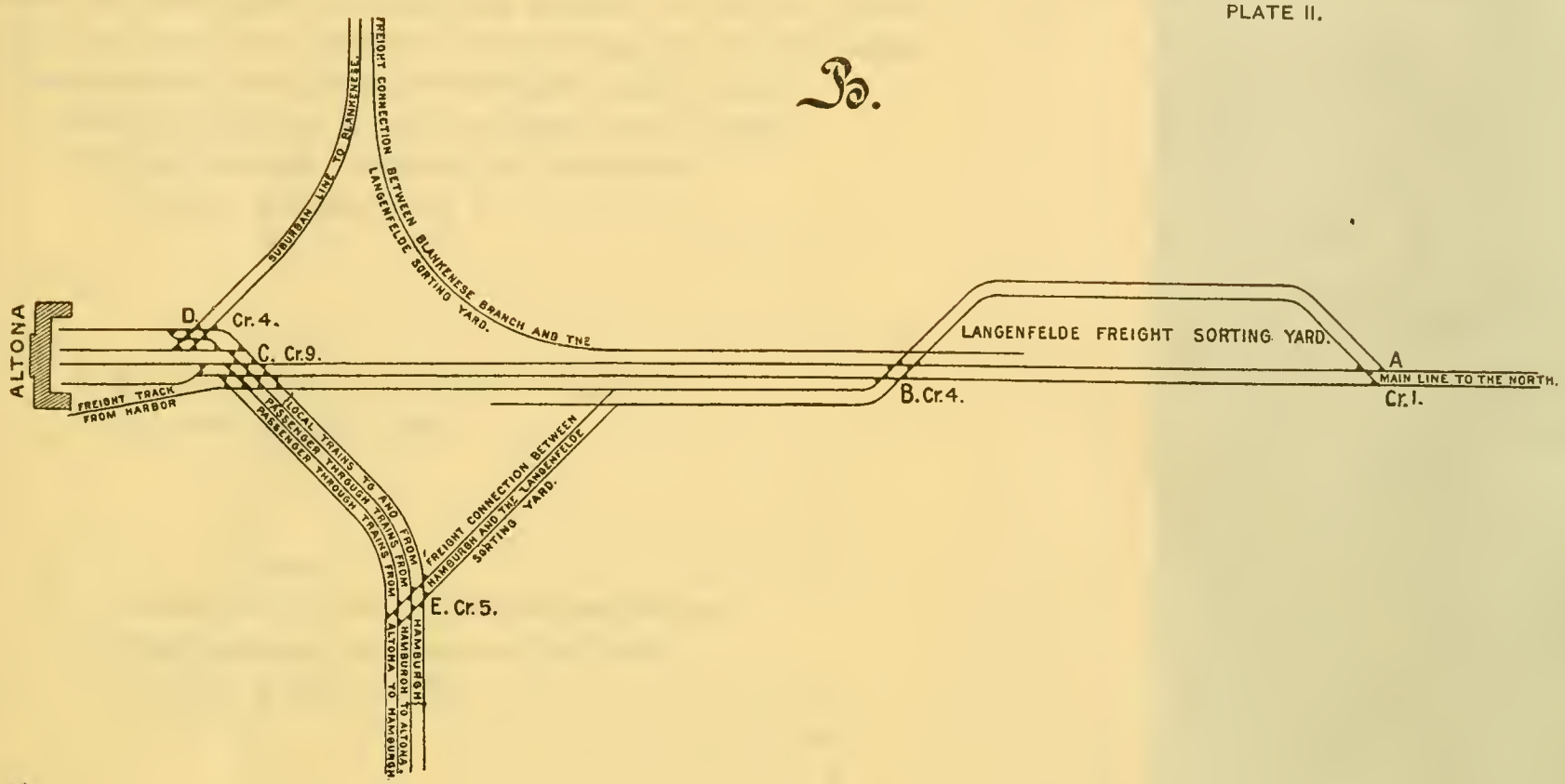
DIAGRAM SHOWING THE CONNECTION OF RAILWAY TRACKS IN COURSE OF CONSTRUCTION AT ALTONA, GERMANY.

— A. —



VOL. XXIX, No. 612.
TRANS. AM. SOC. CIV. ENGRS.
CAESAR ON RAILWAY TERMINAL AT ALTONA.
PLATE II.

B.



C.

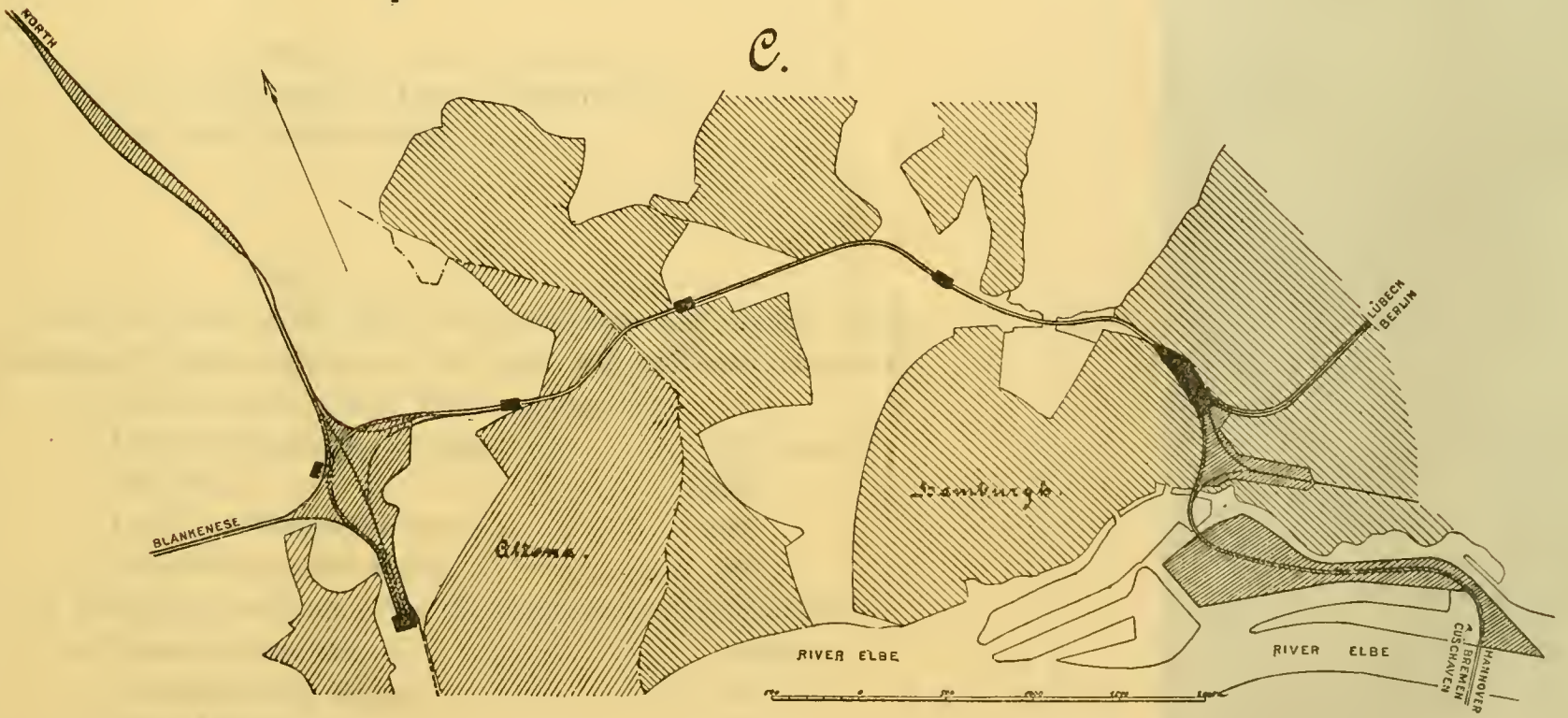


Fig. *B*, Plate II, shows, in an exaggerated plan, what would have arisen had all the grade crossings been retained. If we follow particularly the course of the passenger trains, it appears that the number of crossings with main passenger and freight tracks would be:

I.—For each train on the tracks set apart for city traffic—

1. From Hamburg, *via* Altona, to Blankenese—

At point	*E*	of the	sketch *B*	2
"	*C*	"	"	3
"	*D*	"	"	1
		Total		6

2. From Blankenese, *via* Altona, to Hamburg—

At point	*D*	of the	sketch	1
"	*C*	"	"	3
"	*E*	"	"	2
		Total		6

II.—For each through train on the southern tracks—

1. From Hamburg, *via* Altona, to the North—

At point	*E*	of the	sketch	1
"	*C*	"		3 + 3 = 6
"	*B*	"		2
		Total		9

2. From the North, *via* Altona, to Hamburg—

At point	*A*	of the	sketch	1
"	*B*	"		2
"	*C*	"		3 + 1 = 4
		Total		7

Now, the train traffic upon both passenger and freight tracks, immediately upon completion of the plan, will probably amount to—

A. Passenger trains in both directions together—

a. Upon the Hamburg through tracks..... 200 trains.
City tracks..... 200 "
b. Upon the Blankenese tracks..... 100 "
c. Upon the Northern tracks..... 80 "

B. Freight trains to and from the switchyard at Langenfelde—

a. Towards Hamburg..... 40 trains.
b. Towards Altona Harbor..... 40 "
c. Toward Blankenese..... 10 "

In addition to this, a considerable increase of traffic is certainly to be expected. Under these circumstances, to retain even a part of the above crossings appeared hazardous to the regularity and safety of the traffic. There was, therefore, an arrangement of tracks planned, such as is presented in Plate I. Owing to the great extension of the design, the lengths are drawn to one-half scale compared with the width, and the drawing therefore appears distorted. The course of the several trains is indicated by various kinds of marks.

As may already be seen from the above, it was adhered to as a principle in the project that crossings at grade of two passenger tracks, as well as of a passenger and a freight track, should be avoided. The carrying out of this principle was everywhere successful excepting the point where the freight track, leading from Langenfelde to Bahrenfeld, crosses over into the two Blankenese main tracks. This point lies, however, just at the Bahrenfeld Depot, and these level crossings did not appear hazardous in view of the infrequency of the freight trains—only five in each direction.

For the attainment of the before-mentioned object the preparation of five, in part very comprehensive, structures was necessary (see Nos. 1 to 5, Plate I). Furthermore, the switchyard of Langenfelde had to be placed between the two northern tracks. From the drawing the arrangement of the tracks may be sufficiently understood, and it is only necessary to remark, that in deviation from the usual rule, trains on the city tracks from Structure 5 to Altona Depot, and upon the northward tracks between Structure 1 and the Altona Depot, will run on the left side track.

The location of the side and storage tracks for passenger trains between the through tracks—and, indeed, between the tracks from Hamburg and to the north on one hand, and the tracks from the north and to Hamburg on the other hand—further contributes essentially to the obviation of grade crossings that would occur in hauling and and removing empty trains to and from the six platform tracks, and increases materially the working capacity of the improvement. The difficulty of the project was essentially increased by the fact that all street crossings at grade had also to be abolished, and replaced by over and under crossings.

The project is in course of construction and is about half finished.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

613.

(Vol. XXIX.—August, 1893.)

COMMON ROADS, RAILWAYS AND RIVER COMMUNICATIONS IN PORTUGAL.

By FREDERICO AUGUSTO PIMENTAL, Civil Engineer, of Lisbon, Portugal.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

COMMON ROADS.

Common roads or highways are classified under the following heads : First-class or royal roads, second-class or district roads, and third-class or municipal roads. First-class roads connect Lisbon with the chief towns of the districts and with the principal places on the frontier. Second-class roads connect the above named and the cities and principal towns either with each other or with the railway stations and river ports; and lastly, those of the third class join the townships or *concelhos* with each other or with the preceding roads. The continental part of Portugal is divided into administrative districts, and these into townships or *concelhos*.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The following table shows the total and mean population of each district on the Continent, and its area in square kilometers:

Names of Districts.	Number of townships or *concelhos*.	Area in square kilometers.	Population.	Density of population per square kilometer.
Aveiro	16	2 908.61	290 026	99.71
Beja	14	10 871.28	165 528	15.04
Braga	13	2 738.20	360 151	131.52
Bragança	12	6 669.33	189 592	28.27
Castello Branco	12	6 621.03	208 836	31.54
Coimbra	17	3 883.10	324 330	83.52
Evora	13	7 087.83	121 134	17.09
Faro	15	4 849.95	229 132	47.24
Guarda	14	5 556.63	266 225	47 91
Leiria	12	3 478.15	222 075	63.82
Lisbon	27	7 049.30	613 956	87.11
Portalegre	15	6 431.01	115 546	17.97
Oporto	18	2 292.07	552 865	241.21
Santarem	18	6 861.86	258 888	37.72
Vianna do Castello	10	2 243 44	215 518	96.04
Villa Real	14	4 447.23	239 695	53.89
Vizeu	26	4 922.25	404 203	82.31
	266	88 911.27	4 774 700	53.70

The city of Lisbon has 307 691 inhabitants, and Oporto, 141 924. It was about 1852 that the road system began to have greater development, and since that period to July 30th, 1892, 8 427 km. of royal and district roads, and nearly 2 850 km. of municipal roads, have been constructed.

The length of royal and district roads in the different administrative districts is shown in the table on the next page, in comparison with their area and population.

The length of the first and second class roads in meters is reckoned to be 18 426 791; 7 690 632 m. being first-class, and 10 736 158 m. second-class, roads. The normal width of the first-class roads is 6.6 m., 4.4 m. being for carriage-way and 2.2 m. for bermes; and the width of second-class roads is 6 m., 4 m. being for carriage-way and 2 m. for bermes. These dimensions may be enlarged in the vicinity of great centers or marts, and close to much-frequented railway stations. The maximum gradient allowed for first and second class roads is 5%, and the maximum radius of junction curves, 30 m. The width of third-class or municipal roads is 5 m., 3.5 m. being for carriage-way and 1.5 m. for bermes or footpaths. The maximum slope allowed is 7%, and 10 m. the maximum radius for junction curves.

The cost of construction and maintenance of first and second class roads is defrayed by the State, and to the account of the municipalities belongs that of municipal roads, the State contributing one-third of the amount to be expended, in a strict sense, in their construction. The corporations collect special revenues for municipal roads.

Names of Districts.	Length of Roads In Meters.		
	First and second class roads. Total.	For each square kilometer.	Per 1 000 inhabitants.
Aveiro	537 895	184.90	1 854.60
Beja	364 419	33.50	2 228.48
Braga	610 927	223.10	1 697.00
Bragança	366 698	54.98	1 933.50
Castello Branco	561 093	84.70	2 686.70
Coimbra	639 909	164.79	1 973.00
Evora	413 444	58.33	3 413.11
Faro	363 179	74.80	1 585.10
Guarda	501 598	92.07	1 884.09
Leiria	451 010	129.00	1 296.98
Lisbon	1 294 149	292.50	1 212.40
Portalegre	410 487	63.82	3 552.58
Oporto	670 448	292.50	1 212.40
Santarem	573 442	83.50	2 215.00
Vianna do Castello	388 821	173.30	1 808.40
Villa Real	404 338	80.90	1 684.70
Vizeu	515 447	104.70	1 250.50
	9 067 304	94.78	1 165.01

RAILWAYS.

On December 31st, 1891, there were 2 283.274 km. of working railways, 2 088.653 km. being broad-gauge and 194.621 km. narrow-gauge.

The length of broad-gauge lines under construction was 176.675 km.

Of the length of railways open for traffic, 1 467.960 km. were worked and managed by companies, and 815.314 km. by the State.

The lines worked by companies are divided as follows :

BROAD-GAUGE LINES.

The Royal Company of Portuguese Railways.

	Kilometers.
Lisbon by Elvas to the frontier	275.599
Entroncamento to Oporto	228.873
Carried forward	504.472

	Kilometers.
Brought forward	504.472
Caceres branch line	71.849
Lisbon to Cintra	27.375
Lisbon (Cacem) to Torres Vedras	45.300
Torres to Figueira	151.495
Alfarellos branch line	16.516
Circuit or Circumvallation line	12.856
Lisbon to Cascaes	23.525
Coimbra branch line	1.700
Beira Baixa line	166.000
Total	1 021.088

THE BEIRA ALTA COMPANY.

	Kilometers.
Figueira da Foz to Villar Formoso	252.251

NARROW-GAUGE LINES.

OPORTO TO POVOA AND VILLA NOVA DE FAMALICAO RAILWAY COMPANY.

	Kilometers.
Oporto to Famalicao	57.257

THE BOUGADO AND GUIMARAES RAILWAY COMPANY.

Bougado to Guimaraes	33.135

THE NATIONAL COMPANY.

Foz do Tua to Mirandella	54.679
Vizeu branch line	49.550
Total	104.229

LINES WORKED AND CONSTRUCTED BY THE STATE.

BROAD-GAUGE.

	Kilometers.
Oporto to Valença	131.194
Braga branch line	15.164
Oporto (Ermezinde) to Barca d'Alva	191.766
Custom House branch line	8.916
Barreiro to Pias	195.908
Setubal branch line	12.809
Casa Branca and Extremoz branch line	78.080
Beja to Faro	186.477
Total	815.314

LINES UNDER CONSTRUCTION.

BROAD-GAUGE.

The Royal Company of Portuguese Railways.

	Kilometers.
The Beira Baixa line	45.675

Southern Railways Company.

Vendas Novas to Santarem	71.00
Coimbra to Arganil	60.00

All the roads are single track, with the exception of the railway from Lisbon to Cacem, of that of Cascaes, and of the Eastern line between Lisbon and the Entroncamento at Gollega. The width of the broad-gauge line is 1.67 m. between the inner edges of the rails. The building of Portuguese railways began on September 17th, 1853, and the first section open to traffic was the one between Lisbon and Carregado on the Eastern line.

The technical and economic conditions of the lines worked either by companies or managed by the State are the following:

The Eastern Railway.

This line begins at Lisbon (Caes dos Soldados) and follows along the bank of the Tagus up to Abrantes, where it bends towards Elvas, joining at Badajos the Spanish line. It traverses the administrative districts of Lisbon, Santarem and Portalegre. Its technical conditions, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	183 722.24	66.60
Curves with radius below 400 m	1 026.18	0.40
" " from 400 to 500 m	2 580.34	0.90
" " " 500 to 600 m	11 173.74	4 00
" " " 600 to 700 m	11 451.25	4.10
" " " 700 to 800 m	9 705.19	3.60
" " " 800 to 900 m	7 098.01	2.60
" " " 900 to 1 000 m	7 954.18	2.90
" " above 1 000 m	40 887.87	14.90
Totals	275 599.00	100.00

Grade.	Length in meters.	Percent. of total length.
Level	30 640	11.10
Grades below 0.001	52 900	19.20
" from 0.001 to 0.005	70 500	25 60
" " 0.005 to 0 010	62 259	22.50
" " 0.010 to 0.012	13 400	4.90
" " 0.012 to 0.015	35 800	12.30
" of 0.015	12 100	4.40
Totals	275 599	100.00

The width at formation level in embankment is 5.50 m. and 6.10 m. in cuttings. The road is of double track between Lisbon and the Entroncamento. It has 32 stations, including the one at the junction with the Northern line; that of Abrantes at the junction with the Beira Baixa line, and that of Torre das Vargens on the Caceres embranchment.

The Northern Railway.

The Northern Railway begins at the junction station of the Eastern line, and traverses the administrative districts of Santarem, Leiria, Coimbra, Aveiro and Oporto. Its technical conditions, both in plan and profile, will be found condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	157 862.78	68.97
Curves with radius below 400 m	252.31	0.11
" " from 400 to 500 m	408.05	0.19
" " " 500 to 600 m	10 686.36	4.67
" " " 600 to 700 m	9 433.98	4.12
" " " 700 to 800 m	3 471.22	1.51
" " " 800 to 900 m	2 967.78	1.29
" " " 900 to 1 000 m	9 683.91	4.22
" " above 1 000 m	34 106.81	14.92
Total	228 873 20	100.00

Grade.	Length in meters.	Percent. of total length.
Level	25 792.20	11.22
Grades below 0.001	27 704.40	12.10
" from 0.001 to 0.005	68 600.00	29.97
" " 0.005 to 0.010	53 350.00	23.39
" " 0.010 to 0.012	24 500.00	10.70
" " 0.012 to 0.015	14 692.10	6.41
" above 0.015	14 234.50	6.21
Total	228 873.20	100.00

The width at formation level is the same as that of the Eastern Railway. The line has 22 stations, including those of Alfarellos and Pampilhosa, the first at the junction of the Figueira branch line, and the second belonging to the Beira Alta Railway.

The Eastern and Northern railways have been constructed by the Royal Company, and are to be worked for a period of 99 years by the same, the State granting a subvention or 112 500 francs per kilometer for the Eastern, and 135 000 francs for the Northern, line. This line has five tunnels, measuring altogether 1 701.75 m. in length, and among its numerous constructive works is the remarkable bridge Maria Pia over the Douro, with a single arch of 160 m. span and 37.5 rise, its flooring being 61.30 m. above low water mark.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 by this line was 1 676 692. The number of kilograms of goods transported at high speed was 18 398 841, and at low speed, 759 402 879. The trains have third-class carriages.

The general rates are: 0.1102 franc per kilometer for first class, 0.0857 franc per kilometer for second class, and 0.00613 franc per kilometer for third class.

The 343 km. run between Lisbon (Rocio station) and Oporto is performed by the mail trains in 10 hours 45 minutes, and the 272 km. run between Lisbon and Elvas in 10 hours 46 minutes.

The proportion of passengers in the different classes is as follows: 9.07% of first class, 19.44% of second class, and 71.49% of third class.

The gross earnings per kilometer in the year 1890 amounted to 29 630.4 francs, and the coefficient of the working of the line is 34.98 per cent.

The Caceres Branch Line.

The Caceres branch begins at kilometer 174.8 on the Eastern line at Torre das Vargens station, and following the route to the frontier it joins the Caceres and Madrid line. Its whole length is comprised within the administrative district of Portalegre. It was built by the Royal Company without any charge whatever to the State.

The technical conditions of this line, both in plan and profile, are condensed in the tables on the next page.

The width at formation level is 5 m. in embankment and 5.5 m. in

cuttings. It has five stations, including the one at the commencement of the line.

Alignment.	Length in meters.	Percent. of total length.
Straight	27 830.45	38.28
Curves with radius of 300 m	21 794.85	30.30
" " from 300 to 400 m	8 574.50	11.93
" " " 400 to 500 m	9 178.4	12.76
" " " 500 to 600 m	2 817.8	3.80
" " " 600 to 700 m	702.80	0.92
" " " 1 000 m	950.20	1.92
Totals	71 849.00	100.00

Grade.	Length in meters.	Percent. of total length.
Level	18 536.6	25.93
Grades from 0.001 to 0.005	2 320.0	3.22
" " 0.005 to 0.008	8 358.4	11.49
" " 0.008 to 0.010	5 934 0	8.26
" " 0.010 to 0.012	10 518.0	14.63
" " 0.012 to 0.014	8 241.3	11.47
" " 0.014 to 0.015	5 431.0	7.56
" " 0.015 to 0.018	9 062.4	12.61
" " 0.018 to 0.125	3 447.3	4.83
Totals	71 849.0	100.00

Goods and Passenger Traffic.—The passengers conveyed in the year 1890 by this line were 28 123, and the number of kilograms of goods transported were: at high speed, 871 245 ; at low speed, 45 509 735.

The proportion in the different classes is of 33% for first class, 23% for second class, 44% for third class.

The general rates on this branch line are the same as in force for the Northern and Eastern railways.

Lisbon to Cintra and Torres Vedras, Figueira da Foz and Alfarellos Railway or Western Line.

Lisbon to Cintra.—The line from Lisbon to Cintra begins at Alcantara station, and follows in the direction of Cintra after its junction at Campolide with the City line and at Cacem with the Torres and Figueira Railway.

Its technical conditions are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	14 135.61	51.64
Curves with radius of 320 m	432.10	1.50
" " " 350 m	2 544.68	9.29
" " " 400 m	2 051.23	7.49
" " " 500 m	3 269.98	11.94
" " " 600 m	1 132.74	4.14
" " " 650 m	598.43	2.18
" " " 800 m. and above	3 210.13	11.82
Totals	27 374.90	100.00

Grade.	Length in meters.	Percent. of total length.
Level	7 008.90	25.64
Grades from 0.001 to 0.005	1 650.00	5.80
" " 0.005 to 0.010	2 275.00	8.31
" " 0.010 to 0.012	5 145.55	18.79
" " 0.012 to 0.015	3 686.00	13.56
" " 0.015 to 0.018	7 609.45	27.90
Totals	27 374.90	100.00

The width at formation level is 8.70 m. in cuttings and 9.03 m. in embankment. The road is of double track between Lisbon and Cacem and has three tunnels, their total length being 705 m.

Lisbon (Cacem) to Torres Vedras.—This line commences at the Cacem station (kilometer 19 216.0 of the Cintra Railway), its whole length being comprised within the bounds of the Lisbon administrative district. The line was built by the Royal Company without any charge whatever to the State.

Its technical conditions in plan and profile are summarily contained in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	23 629.16	51.94
Curves with radius of 350 m	3 676 99	8.11
" " " 400 m	5 591.33	12.24
" " from 400 to 500 m	5 509.10	12.16
" " " 600 to 700 m	4 564.52	10.62
" " " 800 to 900 m	262.54	0.58
" " above 900 m	2 066.36	4.35
Totals	45 300.00	100 00

Grade.	Length in meters.	Percent. of total length.
Level	9 376.00	20.73
Grades from 0.000 to 0.005	3 000.00	6.73
" " 0.005 to 0.010	5 857.00	12.72
" " 0.010 to 0.012	3 200.00	7.16
" " 0.012 to 0.015	10 848.00	23.94
" " 0.015 to 0.018	13 019.00	28.72
Totals	45 300.00	100.00

The width at formation level is 5 m. in cuttings and 5.30 m. in embankment. This line has four tunnels measuring 715 m. of total length and eight stations, including the one of Cacem at the junction with the Cintra Railway.

Goods and Passenger Traffic.—The number of passengers conveyed during the year 1890 by the Lisbon, Cintra and Torres Railway amounted to 597 202 ; the number of kilograms of merchandise transported at high speed being 2 144, and at low speed, 651 030.

The proportion of passengers in the different classes was of 14.9% in first class, 30.5% in second class, 44.6% in third class.

The gross earnings per kilometer were 21 036 francs, the coefficient of the working being 57.12 per cent.

Torres Vedras to Figueira da Foz.—This road begins at the terminus of the Lisbon and Torres line and forms its extension to Figueira. It was constructed by the Royal Company and is to be worked by the same for a period of 99 years, the State allowing 5% for completement of interest and payments of 166 667 francs capital per kilometer, the disbursement of the State never exceeding, however, 2 per cent.

This line is laid across the administrative districts of Lisbon, Leiria and Coimbra. Its technical conditions, both in plan and profile, are condensed in the following tables :

Alignment.	Length in meters.	Percent. of total length.
Straight	102 118.70	67.40
Curves with radius of 350 m	235.19	0.15
" " of 400 m	3 571.25	2.35
" " from 400 to 500 m	17 963.00	11.87
" " " 600 to 700 m	10 698.19	7.08
" " " 800 to 900	4 358.13	2.89
" " " 1 000 and above	12 550.70	8.28
Totals	151 495.16	100.00

Grade.	Length in meters.	Percent. of total length.
Level	39 480.38	26.06
Grades from 0.005	28 305.00	18.68
" " 0.005 to 0.010	26 355.00	17.38
" " 0.010 to 0.012	12 852.00	8.48
" " 0 012 to 0.015	43 702.78	28 84
" " 0.015 to 0.018	800.00	0.56
Totals	151 495.16	100.00

The width at formation level is the same as that of the Lisbon line (Cacem-Torres). It has 23 stations, including the one of Torres at its commencement.

Alfarellos Branch Line.—This branch connects the Northern line at kilometer 200, counting from Santa Apolonia station at Lisbon, with the line of Figueira at Amieira station. It was constructed and is worked on the same terms as the line of Torres to Figueira.

The technical conditions of this railroad in plan and profile are condensed in the following tables :

Alignment.	Length in meters.	Percent. of total length.
Straight	8 037.14	48.66
Curves with radius of 300 m	214.67	1.30
" " 400 m	610 63	3.69
" " 500 m	3 411.08	20.65
" " 600 m	2 812.44	17.02
" " 800 m	1 146.32	6.92
" " 1 500 m	283.62	1.76
Totals	16 515.90	100.00

Grade.	Length in meters.	Percent. of total length.
Level	10 264.90	62.15
Grades of 0.005	5 581.00	33.80
" 0.015	670.00	4.05
Totals	16 515.90	100.00

The width at formation level is the same as that of the line from Torres to Figueira. It has three stations, including those of Alfarellos and Amieira.

The passengers conveyed in the year 1890 by the line of Torres to Figueira and by the Alfarellos branch were 285 507, and the number of kilograms of goods transported at full speed amounted to 141 200.

The proportion of passengers in the different classes was of 8.1% in first class, 19.4% in second class, and 72.5% in third class.

The general rates applied to the Lisbon, Cintra, Torres, Figueira and Alfarellos railroads are, 0.1102 franc per kilometer for first class; 0.0857 franc per kilometer for second class, and 0.00613 franc per kilometer for third class.

The gross earnings in 1890 amounted to 10 381.3 francs per kilometer, the coefficient of the working being 68.12 per cent.

The City and Circuit Lines.

The Circuit line connects the Eastern and the Cintra railways with the Rocio station within the city of Lisbon. Its total length is 12 856 m.

The Circuit line, or, as it is more commonly called, the Circumvallation line, has a tunnel 180.5 m. in length, and the City line another, 2 600 m. in length. Both lines were constructed by the Royal Company without any charge to the State.

The Cascaes Railway.

The Cascaes Railway begins at Alcantara station in Lisbon, and, following along the right bank of the Tagus, puts in easy communication with the capital the watering-places bordering on the river and those of Estoril and Cascaes at its terminus. It was constructed by the Royal Company without any charge to the State. This road is of double track between Pedrouços and Cascaes.

Its technical conditions in plan and profile are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	15 601.68	66.30
Curves with radius from 201 to 300 m	214.68	0.90
" " " 300 to 400 m	4 518.34	19.20
" " " 400 to 600 m	2 765.41	11.70
" " above 600 m	425.23	1.90
Totals	23 525.34	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 437.43	61.30
Grade from 0.000 to 0.005	2 708.61	11.50
" " 0.005 to 0.010	1 628.00	6 90
" " 0.010 to 0.014	4 751.30	20.30
Totals	23 525 34	100.00

This railroad has 14 stations, including that of departure, and its general rates are collected by sections, the line being divided into three.

Rates: first class, 0.888 franc; second class, 0.444 franc; third class, 0.277 franc.

Passenger Traffic.—The number of passengers conveyed by the line amounted to 615 592 in the following proportions: 14 339 first-class passengers, or 2.32%; 285 564 second-class passengers, or 46.38%; 315 689 third-class passengers, or 51.30 per cent.

The Beira Baixa Railway.

This line commences at the station of Abrantes, on the Eastern railroad, 31.33 m. above the mean level of the sea, running thence along the right bank of the Tagus up to Portas de Rodao, where it attains the altitude of 107.211 m. above the said level. From this point it pursues its course by the neighborhoods of Castello Branco and Covilha to the vicinity of Guarda, where it ends at the altitude of 811.567 m. in the Beira Alta Railway, after crossing the administrative districts of Santarem, Castello Branco and Guarda.

It was constructed by the Royal Company, the State allowing the same company 5.5% for interest and payment of cost, which, according to the contract, was at the rate of 198 888 francs per kilometer.

The technical conditions of this railway, both in plan and profile, may be condensed in the tables on the next page.

The width at formation level on the upper surface of the embankments is 5.30 m. and of 5 m. in the cuttings. Besides numerous constructive works, this railway has 10 tunnels, the aggregate length of which is 1 981.50 m. The stations are 24 in number, including that of Abrantes, which serves at the same time the Eastern Railway, and the Guarda station, which belongs in common to the Beira Alta line.

Alignment.	Length in meters.	Percent. of total length.
Straight	135 343.64	63.93
Curves with radius of 300 m	32 915.43	15.55
" " from 300 to 400 m	24 346.55	11.50
" " " 400 to 600 m	14 740.42	6.96
" " above 600 m	4 329.36	2.06
Totals	211 675.40	100.00

Grade.	Length in meters.	Percent. of total length.
Level	89 085.83	42.08
Grades from 0.005	14 868.00	7 02
" " 0.005 to 0.010	13 845.00	6.51
" " 0.010 to 0.015	23 968.00	11.32
" " 0.015 to 0.018	69 908.57	33.07
Totals	211 675.40	100.00

This railway was still in course of building in 1890, and on September 7th, 1891, 166 km. were open to circulation between Abrantes and Covilha.

Besides the roads described the Royal Company has at its charge the working of a broad-gauge branch connecting the Coimbra station with the heart of the town, and which is destined to serve as terminus to the Arganil line, at present under construction. This branch is 1 700 m. in length.

The Southern and South-Eastern Railways.

The Southern and South-eastern lines have both their common origin at Barreiro, on the left bank of the Tagus. The main line leads to the Algarve, its terminus being at Faro, the capital of the district bearing this name. A branch extends to the town of Setubal, and another to Extremoz, which passes near Evora, extending from thence to Beja and Pias. These railways cross the administrative districts of Lisbon, Evora, Beja and Faro. The main line and its branches are owned and managed by the State. The width of the track is 1.67 m. between the inner edges of the rails.

The technical conditions of its various parts, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	148 465.37	76.24
Curves with radius from 300 to 350 m	1 391.72	0.71
" " " 350 to 400 m	4 465.84	2.26
" " " 400 to 600 m	3 963 22	2.02
" " " 600 to 800 m	3 341.75	1.55
" " " 800 to 1 000 m	214.00	0.01
" " above 1 000 m	34 066.64	17.21
Totals	195 908.54	100.00

Grade.	Length in meters.	Percent. of total length.
Level	31 679.09	16.13
Grades from 0 005	51 542.50	26.33
" " 0.005 to 0.010	94 996.05	48.49
" " 0.010 to 0 015	15 033.41	7 67
" " 0.015 to 0.016	2 657.49	1.32
Totals	195 908.54	100.00

The Setubal Branch Line.

This branch begins at Pinhal Novo station and ends at Setubal, after a course of 12 809.60 m. Its length in straight alignment is 8 538.96 m., and 4 270.64 m. in curved alignments, which is equivalent to 66.6% of the first and to 33.4% of the second, for its whole extent.

The technical conditions of the profile may be seen in the following table:

Grade.	Length in meters.	Percent. of total length.
Straight	557.30	4.35
Grades from 0.005	6 349.64	49.72
" " 0.005 to 0.010	5 902 66	45 93
Totals	12 809.60	100.00

The Casa Branca and Extremoz Branch Line.

This line begins at Casa Branca station and ends at the town of Extremoz, after passing close to the city of Evora. Its technical conditions, both of plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	47 227.56	60.48
Curves with radius of 300 m	1 263.60	1.61
" " of 350 m	475.46	0 51
" " from 400 to 450 m.	13 788.63	17.65
" " " 600 to 750 m.	3 623 87	4.64
" " " 750 to 800 m.	1 948.73	2.49
" " above 1 000	9 751.95	12.62
Totals	78 079.80	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 926.70	19.11
Grades from 0 005	16 413.60	21.02
" " 0.005 to 0.010	22 716.86	29.09
" " 0.010 to 0 015	24 022.64	30.78
Totals	78 079.80	100.00

Beja and Faro Railway.

It is at Beja station that the line of the Algarve bends towards that province, ending at Faro after a run of 186 477.32 m. In its first section from Beja to Casevel, 46 682 m. in length, it has 16 774 m. in curved alignments, or 35.98% of its whole extent.

The technical conditions of this line in profile are condensed in the following tables:

Grade.	Length in meters.	Percent. of total length.
Level	5 084.0	10.90
Grades from 0.005	10 357.0	22.22
" " 0 005 to 0.010	17 423.0	37.36
" " 0.010 to 0.015	10 973.0	23.53
" " 0.015 to 0 018	2 791.0	5.99
Totals	46 628.0	100.00

The Casevel and Faro Section.

The technical conditions of this section of the main line, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	85 073.35	60.82
Curves with radius of 300 m	12 877 51	9 21
" " from 300 to 400 m	16 001.43	11.44
" " " 400 to 600 m	13 062.73	9.34
" " above 600 m	12 834.30	9.19
Totals	139 849.32	100.00

Grade.	Length in meters.	Percent. of total length.
Level	26 485.75	18.94
Grades from 0.005	16 363.50	11.71
" " 0.005 to 0.010	22 883.63	16.38
" " 0.010 to 0.018	74 116.44	52.97
Totals	139 849.32	100.00

The width at formation level in embankment measures 5.30 m. and 6.20 m. in cuttings. It has 45 stations, of which 32 belong to the main line from Barreiro to Faro, 2 to the Extremoz branch, 7 to that of Setubal, and 4 to the extension from Beja to Pias.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was of 340 915, and the amount of metrical tons of merchandise transported at low speed 158 404.

The run between Barreiro and Faro for a length of 340 km. is accomplished by mail trains in 12 hours 25 minutes. The general passenger fares are : 0.105 franc per kilometer for first class, 0.0815 franc per kilometer for second class, and 0.059 franc per kilometer for third class.

The gross earnings for 1890 amounted to 7.973 francs per kilometer and the coefficient of the working was 62.08 per cent.

The Minho Railway.

The Minho Railway begins at Oporto, where it is joined by the Northern line, and follows its course through the province of Minho,

serving its cities and principal towns, such as Braga, Barcellos, Vianna up to Valença, where it joins, by means of the international bridge over the river of the same name, with the Spanish line of Orense and Vigo. It is 131 194.52 m. in length. The city of Braga is reached by a branch line 15 163.71 m. in length.

This railway was built and is worked directly by the State. Its course lies through the districts of Oporto, Braga and Vianna do Castello.

The technical conditions, both in plan and profile, either of the main line or of the Braga branch, may be found condensed in the following tables :

Alignment.	Length in meters.	Percent. of total length.
Straight	88 481.07	67.44
Curves with radius from 300 to 400 m	7 502.48	5.71
" " " 400 to 500 m	8 765.95	6.67
" " " 500 to 600 m	4 729.31	3.60
" " above 600 m	21 715.71	16.58
Totals	131 194.52	100.00

Grade.	Length in meters.	Percent. of total length.
Level	38 726.02	29.51
Grades from 0.005	18 714 88	14.26
" " 0.005 to 0.010	14 878 06	11.34
" " 0.010 to 0.012	12 388.21	9.44
" " 0.012 to 0.015	46 487.35	35.45
Total	131 194.52	100.00

The Braga Branch Line.

Alignment.	Length in meters.	Percent. of total length.
Straight	8 905.36	58.72
Curves with radius of 400 m	1 238.61	8.16
" " " 400 to 500 m	822.04	5.42
" " " 500 to 600 m	733.40	4.83
" " above 600 m	3 464.30	22.87
Totals	15 163.71	100.00

Grade.	Length in meters.	Percent. of total length.
Level	3 872.24	25.53
Grades from 0.005 to 0.010	2 641.97	17.42
" " 0.010 to 0.015	6 604.43	43.55
" " 0.015 to 0.016	2 005 07	13.50
Totals	15 123.71	100.00

The width at formation level in embankment is 5.30 m. and 4.50 m. in cuttings. This line has, besides some important constructive works, six tunnels, the aggregate length of which is 2 174.90 m.

Goods and Passenger Traffic.—During the year 1890, 554 387 passengers were conveyed by this line, and the amount of goods transported at low speed was of 100 824.429 metrical tons.

The proportion of passengers in the different classes were as follows: 8.28% of first class, 17.57% of second class, and 74.15% of third class. There are 30 stations on the Oporto and Valença route, and five on the Braga branch, including one common to the main line. The general rates for passengers were: 0.105 franc per kilometer for first class, 0.0813 franc per kilometer for second class, and 0.059 franc per kilometer for third class.

The run on this line is accomplished by mail trains in 5 hours 18 minutes.

The Douro Railway.

The Douro line begins at the station of Ermezinde, on the Minho railroad, distant 8 426 m. from the city of Oporto, and crossing the province of Minho, enters afterwards in the Douro valley, through which it pursues its course to the border of the kingdom, joining there the Salamanca Railway by means of a bridge over the River Agueda. Its course lies through the Oporto, Villa Real and Bragança districts, bordering also on those of Vizeu and Guarda. It was constructed and is worked directly by the State.

Better to appreciate the technical conditions of this line, we shall divide it into two sections, the first from its commencement to Pinhao station on the right bank of the Douro, and the second from this point to its terminus on the frontier.

Section of the Douro Railway from Ermezinde to Pinhao.

Alignment.	Length in meters.	Percent. of total length.
Straight	69 266.71	58.25
Curves with radius of 250 m	2 120.79	1.78
" " from 250 to 400 m	22 444.27	18.87
" " " 400 to 800 m	18 913.31	15.82
" " above 800 m	6.171.61	5.28
Totals	118 916.69	100.00

Grade.	Length in meters.	Percent. of total length.
Level	40 579.23	34.12
Grades from 0 010	27 306.02	22.96
" " 0.010 to 0.014	20 404.59	17.20
" " 0.014 to 0.016	30 626.85	25.72
Totals	118 916.69	100.00

Section Between Pinhao and Barca d'Alva.

Alignment.	Length in meters.	Percent. of total length.
Straight	42 327.399	58.24
Curves with radius of 250 m	1 659.74	2.28
" " from 250 to 300 m	14 973.69	20.55
" " " 300 to 400 m	4 803.08	6.59
" " " 400 to 500 m	3 965.65	5.44
" " " 500 to 600 m	1 894 97	2.60
" " above 600 m	3 224.84	4.30
Totals	72 849.369	100.00

Grade.	Length in meters.	Percent. of total length.
Level	30 418.829	41.75
Grades from 0.005	36 696.210	50.37
" 0.005 to 0.010	2 741.00	3.76
" 0.010 to 0.015	2 993.33	4.12
Totals	72 849.369	100.00

The width at formation level is of 5.3 m. in embankment and 5 m. in cuttings.

Besides numerous constructive works, this line has 23 tunnels, the total length of which is 6 914 m.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was of 345 902, and the number of tons of merchandise at low speed 137 120.950.

The gross earnings of the Minho and Douro railways were 14 396.6 francs per kilometer, and the coefficient of the working 55 per cent.

The number of stations is 36. The general rates are the same as those in force on the Minho line. As a dependence of the Minho and Douro lines, the State constructed a branch line connecting the Oporto station with the custom house 3 915.92 m. in length.

This branch line has three tunnels, the total length of which is 1 377.36 m.

The Beira Alta Railway.

This line begins at the town of Figueira, joining the northern line at the Pampilhosa station, and its terminus is at Villar Formoso on the Spanish frontier, where it effects its junction with the Salamanca railway. The road crosses the mountain of Bussaco, where it gains the altitude of 215 m. above the level of the sea, passing in the vicinity of the city of Guarda, where the altitude attained is of 809 m. Besides serving a large tract of land, this line constitutes the shortest route from the central part of Portugal to the north of Spain. This railway was constructed and is worked by the Beira Alta Company, the State granting a kilometric subvention of 127 777 francs for the length of 202 207.14 m. from Pampilhosa to the frontier, the section from that point to Figueira, 50 044.66 m. in length, being constructed without any charge to the State. It crosses the administrative districts of Coimbra, Aveiro, Vianna and Guarda.

The technical conditions of this line, both in plan and profile, are condensed in the following tables :

Alignment.	Length in meters.	Percent. of total length.
Straight	143 896.73	57.04
Curves with radius of 350 m	22 418.64	8.89
" " of 400 m	15 499.14	6.15
" " from 400 to 500 m	23 027.48	9.13
" " " 500 to 650 m	11 960.08	4.73
" " " 650 to 900 m	10 175.42	4.04
" " above 900 m	25 274.31	10.02
Totals	252 251.80	100.00

Grade.	Length in meters.	Percent. of total length.
Level	66, 767.39	26.46
Grades from 0.005	21 175.00	8.40
" 0.005 to 0.010	33 598.09	13.34
" 0.010 to 0.012	20 796.92	8.24
" 0.012 to 0.014	42 376.00	16.79
" 0.014 to 0.015	67 538.40	26.77
Totals	252 251.80	100.00

The width at formation level is 5.40 m. in embankment and 5 m. in cuttings. There are many and most important constructive works on this line and 13 tunnels with the aggregate length of 3 822.62 m. The stations are 27 in number, including that of Pampilhosa which is common to the Northern line.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 was 227 216, and the number of tons of merchandise at low speed, 102 875.

The proportion of passengers in the different classes was of 6.92% for first class, 16.53% for second class, and 76.44% for third class.

The gross earnings in 1890 amounted to 8 197 francs and the coefficient of the working was 46.2 per cent.

The run of trains between Figueira and Villar Formoso is accomplished in 11 hours, including the stoppage of 45 minutes at Pampilhosa.

NARROW-GAUGE RAILWAYS.

Line from Oporto by Povoa de Varzim to Villa Nova de Famalicao.

This line, beginning at Oporto, follows by the seaside to Povoa de Varzim, where it bends towards Villa Nova de Famalicao, joining there the Minho Railway. Its technical conditions, both in plan and profile, are condensed in the following tables, the line having been built and being worked without any charge to the State.

Alignment.	Length in meters.	Percent. of total length.
Straight	46 136.98	80.57
Curves with radius of 100 m	151.80	0.26
" " from 100 to 200 m	1 737.00	3.03
" " " 200 to 300 m	4 575.58	8.00
" " " 300 to 400 m	2 448.00	4.26
" " " 400 to 500 m	1 475.71	2.57
" " above 500 m	750.15	1.31
Totals	57275.22	100.00

Grade.	Length in meters.	Percent. of total length.
Level	13 644.58	23.82
Grades from 0.005	4 310.26	7.53
" " 0.005 to 0.010	8 617.08	15.04
" " 0.010 to 0.015	7 912.90	13.83
" " 0.015 to 0.238	22 790.40	39.78
Totals	57 275.22	100.00

The width of the line of way is 0.90 m. between the inner edges of the rails, the width at formation level in embankment being 3.50 m. and 4 m. in cuttings. This railroad has 17 stations.

Goods and Passenger Traffic.—The number of passengers conveyed by this line during the year 1890 was 351 286, and the tons of merchandise transported at low speed were 18 880. The gross earnings in the same period amounted to 7 870 francs per kilometer, the coefficient of the workings being 58.91. The general rates are 0.15 franc per kilometer for first class and 0.088 franc per kilometer for second class.

The Bougado and Guimaraes Railway.

This line begins at Trofa station, on the Minho Railway, and, following by the valley of the River Ave, serves the town of Santo Thyrso and the watering-place of Vizella, bending thence towards Guimaraes, where it ends. It was constructed and is worked by the Bougado Company without any charge to the State.

Its technical conditions are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	18 397.10	55.52
Curves with radius of 200 m	6 096.36	18.39
" " from 200 to 300 m	2 653.73	8.00
" " " 300 to 500 m	3 511.64	10.60
" " above 500 m	2 476 57	7.49
Totals	33 135.40	100.00

Grade.	Length in meters.	Percent. of total length.
Level	6 419.06	19.37
Grades from 0.005	6 455.49	19.48
" " 0.005 to 0.010	8 595.53	25.95
" " 0.010 to 0.015	4 587.54	13.84
" " 0.015 to 0.019	7 077.78	21.36
Totals	33 135.40	100.00

The width of the line of way is 1 m., and that at formation level in cuttings 3.60 m. It has 14 stations.

Goods and Passenger Traffic.—In the year 1890 the number of passengers conveyed by this line was 177 792, and the number of tons of merchandise transported at low speed amounted to 364 631. The general rates are 0.116 franc per kilometer for first class and 0.064 franc per kilometer for second class. The gross kilometric earnings were 9 684.5 francs, and the coefficient of the workings 4.95 per cent.

The Foz do Tua and Mirandella Railway.

This line begins at Fos do Tua station on the Douro Railway, and, following its course by the left bank of the River Tua, ends at Mirandella, after a run of 54 699.64 m. It was built by the National Company (*Companhia nacional*), the Government allowing a guarantee of 5.5% on 109 401 francs, kilometric cost calculated.

The technical conditions, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	34 381.72	62.89
Curves with radius of 150 m	2 023.22	3.74
" " from 150 to 200 m	8 703.25	16.09
" " " 200 to 250 m	2 917 84	5.39
" " " 250 to 300 m	3 369.73	6.03
" " " 300 to 400 m	1 670.78	3.09
" " above 400 m	1 613.21	2.77
Totals	54 679.75	100.00

Grade.	Length in meters.	Percent. of total length.
Level	26 382.65	48.24
Grades from 0 005	12 782.58	23.37
" " 0.005 to 0.010	7 700.01	14.12
" " 0.010 to 0.015	3 813.05	7.00
" " 0.015 to 0.0175	4 001.46	7.27
Totals	54 679 75	100.00

The width of the line of way is 1 m. between the inner edges of the rails, and that at formation level 3.50 m. in embankment and

4.30 m. in cuttings. Besides numerous constructive works, there are six tunnels, the aggregate length of which is 541.75 m.

It has 12 stations.

Goods and Passenger Traffic.—The number of passengers conveyed in the year 1890 was of 33 581, and the amount of goods traffic, 17 327 463 kg.

The proportion of passengers was: For first class, 8%; for second class, 13%; for third class, 79 per cent. The general rates are: 0.105 franc per kilometer for first class; 0.0888 franc per kilometer for second class. The gross earnings per kilometer were, in 1890, 3 888 francs, and the coefficient of the working, 85 per cent.

The Vizeu Branch Line.

This branch line commences at Santa Comba station, on the Beira Alta line, and ends at Vizeu, its length being 49 550.23 m. It was constructed and is worked by the National Company, the Government giving a guarantee of 5.5% for interest and payments of capital, which is of 127 111 francs per kilometer.

The technical conditions of this line, both in plan and profile, are condensed in the following tables:

Alignment.	Length in meters.	Percent. of total length.
Straight	29 226 23	58.98
Curve with radius in 150 m	977.1	1 97
" " from 150 to 200 m	11 884.1	23 98
" " " 200 to 300 m	5 515.79	11.13
" " " 300 to 400 m	756 46	1.52
" " above 400 m	1 190.55	2 42
Totals	49 550.23	100.00

Grade.	Length in meters.	Percent. of total length.
Level	14 421.11	29.10
Grades from 0.010	3 033.71	6.12
" " 0.010 to 0.012	3 150.80	6.35
" " 0.012 to 0.015	12 999.21	26.11
" " 0.015 to 0.018	15 945.40	32.32
Totals	49 550.23	100 00

The width of the line of way is 1 m. between the inner edges of the rails. The width at formation level in embankment is 4 m., and

4.30 m. in cuttings. This line has 12 stations, including the one of Santa Comba, on the Beira Alta Railway. The general rates are the same as those in force on the Mirandella line.

NAVIGABLE WAYS.

Besides highways and railways, the country has some navigable rivers, the following being the most important :

	Kilometers.
Minho, navigable for the length of	51
Lima, navigable for the length of	38
Douro, navigable for the length of	200
Vouga and Aveiro estuary	80
Mondego	124
Tagus	265
Sado	75
Mira	25
Portimao	20
Guadiana	70
Azambuja, Benavente and Salvaterra canals	42
Total	990

Influence of Means of Communication in the Economic Development of the Country.—Considering that the means of communication are the most prominent factors in the economic existence of nations, it was thought advisable to give some statistical data, with the purpose of showing what has been the influence exercised in the country by such means on comparing the years 1851 and 1890.

Maritime Trade, 1851—

Number of vessels which entered the ports of the Continent carrying freight or in ballast	7 395
Vessels cleared	7 830
Total	15 225

	Tons.
Tonnage of vessels entered	500 671
Tonnage of vessels cleared	542 040
Total	1 042 711

1890.

	Tons.
Number of steam vessels entered carrying freight, 2 728	3 526 383
Steam vessels entered in ballast, 782	1 065 999
Number of sailing vessels entered carrying freight, 1 139	239 813
Sailing vessels entered in ballast, 1 126	62 175
Number of steam vessels cleared carrying freight, 2 650	3 591 366
Steam vessels cleared in ballast, 840	982 144
Number of sailing vessels cleared carrying freight, 1 670	219 341
Sailing vessels cleared in ballast, 819	84 290

Commercial Trade, 1851—

	Francs.
Importation	76 384 650
Exportation	45 713 758
Re-exportation	13 624 234

1890.

Importation	326 876 666
Exportation	178 207 222
Re-exportation	38 535 555
Transit	23 126 111

Public Revenue—

Direct and indirect taxation, 1851	57 111 112
Direct and indirect taxation, 1890	208 805 556

The country continues contributing to its economic development, by giving impulse to the enlargement of the common road and railway systems, and by improving its seaports and other navigable means of transportation.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

614.

(Vol. XXIX.—August, 1893.)

THE RAILWAY SYSTEM OF NEW SOUTH WALES.

By THOMAS FLETCHER BIRRELL, Civil Engineer, Newcastle, New South Wales.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Railways and rivers are the two great channels of inland intercommunication available for a people's enterprise. Some countries are, fortunately for themselves, well favored by the endowment of Nature with one of these aids of development. Australia has not been so fortunate. Our water-courses, with the exception of a few, are neither navigable nor large, and even such as we have are only available under certain circumstances. It is some evidence of our enterprise and determination as a people that, since the sod of the first railway was turned in Australia, a little over 40 years ago, we have never relaxed in our persistent efforts to link all parts of the eastern side of the continent together with iron bands. As the beginnings of coloni-

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

zation had its rise in New South Wales, so of course had the Australian system, and it is important to notice that the beginning was quite in conformity with English ideas.

Nearly all our railways are public property, but they began in an attempt at private enterprise. The change has not been due to any economical theorizing, but to a compulsion of circumstances. The colonists were not rich enough for the work, and English capitalists were not at that time awake to the opportunity, and what private enterprise began drifted unavoidably into the hands of the Government. Our railway policy has been made for us rather than by us.

Sixteen years after the opening of the first railway line in England, a public meeting was called in Sydney to discuss the question of railway communication. The idea was well received, and a committee appointed to inquire into the railway question and the cost of constructing an experimental line; and it brought up a report to the effect that a line could be laid from Sydney to Goulburn at a cost of about £6 000 per mile, to yield a profit of 8 per cent. Early in 1848 the survey of the proposed line was completed. A petition was drawn up and presented to the Legislative Council of New South Wales, which referred it to a select committee. On the report of this committee, resolutions were passed by the Council averring that the time was ripe for the inception of a scheme of railway enterprise. Up to this time there had apparently been no idea of the interference by the State in the work of construction, and so far was this from the thought of the committee that a recommendation was appended to its report, that the Government should offer some premium for the encouragement of private enterprise. In November, a provisional committee was appointed and a prospectus issued setting forth the scope of the proposed "Sydney Tramroad and Railway Company" with a capital of £100 000 and interest guaranteed by the Government for 10 years at the rate of 5 per cent. The scrip of the company was promptly taken up, although its aim met with a certain amount of opposition, and some difficulty was at first experienced in galvanizing the public mind into a practical interest in what was then so novel an enterprise. When the first general meeting of shareholders was called in November, 1849, it was found that the affairs of the company were in fair working order. By December a survey had been made to Parramatta and Liverpool, and in January of the next year the directors in

their first report were able to congratulate the shareholders on the prospects of the enterprise in which they were engaged. On July 3d, 1850, the Sydney Railway Company invited the then Governor, Sir Charles Augustus Fitzroy, to witness at Redfern the turning of the first sod of the great railway system of the Australian Continent by the hands of his daughter, the Hon. Mrs. Keith Stuart, in the presence of an enthusiastic concourse of spectators. This was a brilliant commencement. But the company soon found that the heavy drain upon its resources and the necessarily unproductive expenses they were daily incurring began to seriously discourage the shareholders and the public, and very soon they complained that the support of the Government was the only thing that continued to hold the nascent enterprise together. The first contract let was from Rookwood towards Sydney, and the work went on until the gold discovery and the rush of population to the gold fields, with the consequent rise in the price of labor and materials, compelled the company to release the contractors from their obligations.

Another contract was let to carry the work to Ashfield, and thence to Parramatta; 500 navvies were imported, and an additional State loan of £150 000 obtained, with the provision that the Government had power to name one-half of the directors, who had hitherto been elected by the shareholders. This was the first step towards the Government taking the enterprise into its own hands. In January, 1854, the directors announced at a meeting that the cost of the line to Parramatta would exceed the original estimate, owing to the price of labor and material, from £218 240, as estimated in 1852, to £320 000, besides £97 000 for Darling Harbor Works. The capital was increased by £100 000, and another loan of £150 000 was obtained from the State on the same conditions as before. By January of the next year the estimate for the Parramatta line had risen to £500 000, and the shareholders were convinced at last that the prospects of profit on their courageous enterprise had finally disappeared.

In 1853 another movement was initiated to carry a railway line from Newcastle to Maitland, a provisional committee being formed and a capital of £100 000 subscribed immediately. In the course of 12 months, however, this company also found the work beyond its powers, and the inevitable result came to pass in the taking over of the affairs of both companies by the Government of New South Wales

in the year 1854. More money and renewed vigor were put into the enterprise under State management, and in September, 1855, five years after the first sod was turned, and nine years after the railway project was mooted, the line from Sydney to Parramatta was declared open for traffic, and the Government Railway System of New South Wales practically inaugurated at last.

But, although the railway system had its inception in New South Wales, it was in Victoria that the first line was open for actual traffic. The line from Melbourne to Sandridge was not commenced until January, 1853. It was constructed by a private company, and in September, 1854, the line was opened. The first section of the South Australian Railway was from Adelaide to Gawler, which was opened in October, 1857, the distance being 25 miles.

In New Zealand the first railway line thrown open was at Lyttleton (Canterbury District) in December, 1863. Queensland followed on July 31st, 1865, with a line from Toowoombah to Ipswich. Tasmania opened its first section on August 19th, 1869, and the first sod of the West Australian Railway was turned by Governor Weld on November 22d, 1874. The progress in all the colonies has been in every way wonderful, when the sparseness of the population and their resources are taken into consideration. In New South Wales, after the opening of the first short line, the work of railway construction languished for at least 20 years, though only three were allowed to pass without at least some progress being made. These exceptions were the years 1859, 1865, 1866. When two decades had passed, only 437 miles of railway were open in New South Wales, and at the end of 1892 the total length of railway lines in the Colony was 2 359 miles. To this must be added the private line between Moama and Deniliquin, connecting with the traffic from Echuca. The cost of Government lines up to 1893 amounted to over £30 000 000.

The routes are known as the Great Northern, Great Western and Great Southern lines. The first, which for many years had its termination at Newcastle, has now been connected with Sydney, and one of the great works is the bridge over the Hawkesbury River. (This bridge was started in September, 1886, and finished in April, 1889, and cost £400 000. The contractors were the Union Bridge Company of New York.) This line runs through the Newcastle coal district, the agricultural valley of the Hunter River, the rich pastoral country

of New England, connecting with the line to Brisbane on reaching the Queensland border.

The Great Western line passes over that marvel of engineering skill known as the Zig Zag, and passes on by Bathurst and Dubbo to Bourke.

The Great Southern line branches from the junction at Granville, and traverses the southern districts through Goulburn and Wagga Wagga and other principal towns on the route to Albury, where a junction is effected with the Victorian line to Melbourne. The connection of the two chief cities, the most important feat in railway construction in Australia, was finally effected by a bridge over the River Murray at Wodonga in 1883. Besides these main lines there are many branch lines.

In New South Wales the standard gauge is 4 ft. 8½ ins.; in Queensland, 3 ft. 6 ins., and in Victoria, 5 ft. 3 ins. On both the New South Wales frontiers there is therefore a break of gauge.

It is now proposed to consider the railway system of New South Wales, and to compare it briefly with the railway systems of England and America.

The Road.—It would be impossible, in a paper like the present, to go into all the details of modern railway construction, so it is proposed to consider one or two points, and then deal somewhat fully with the various forms of permanent way. One matter which has been too often overlooked by engineers, when constructing lines with sharp curves, is the question of easing off the junction of the straight and curved portions of railways, and the junction of reversed curves by a gradual increase of curvatures. Engineers are fully alive to the advantages of easing of curves, and the custom of introducing transition curves is fast becoming universal. The disagreeable "lurch" which is felt on entering sharp curves is only too well known to those who travel on lines like those of New South Wales. The railways of this colony are most exceptional in their character, having been constructed with an enormous proportion of steep gradients, the worst grades being on the trunk lines and so situated that the whole volume of traffic has to pass over them.

The difficulties surrounding the working of this colony's railways, having more than 2 000 miles of single line and exceptionally sharp curves—and the steepest grades being also on the main lines—will

be readily understood when it is said that there are 629 miles of grades, varying from 1 in 30 to 1 in 75 in the following proportions:

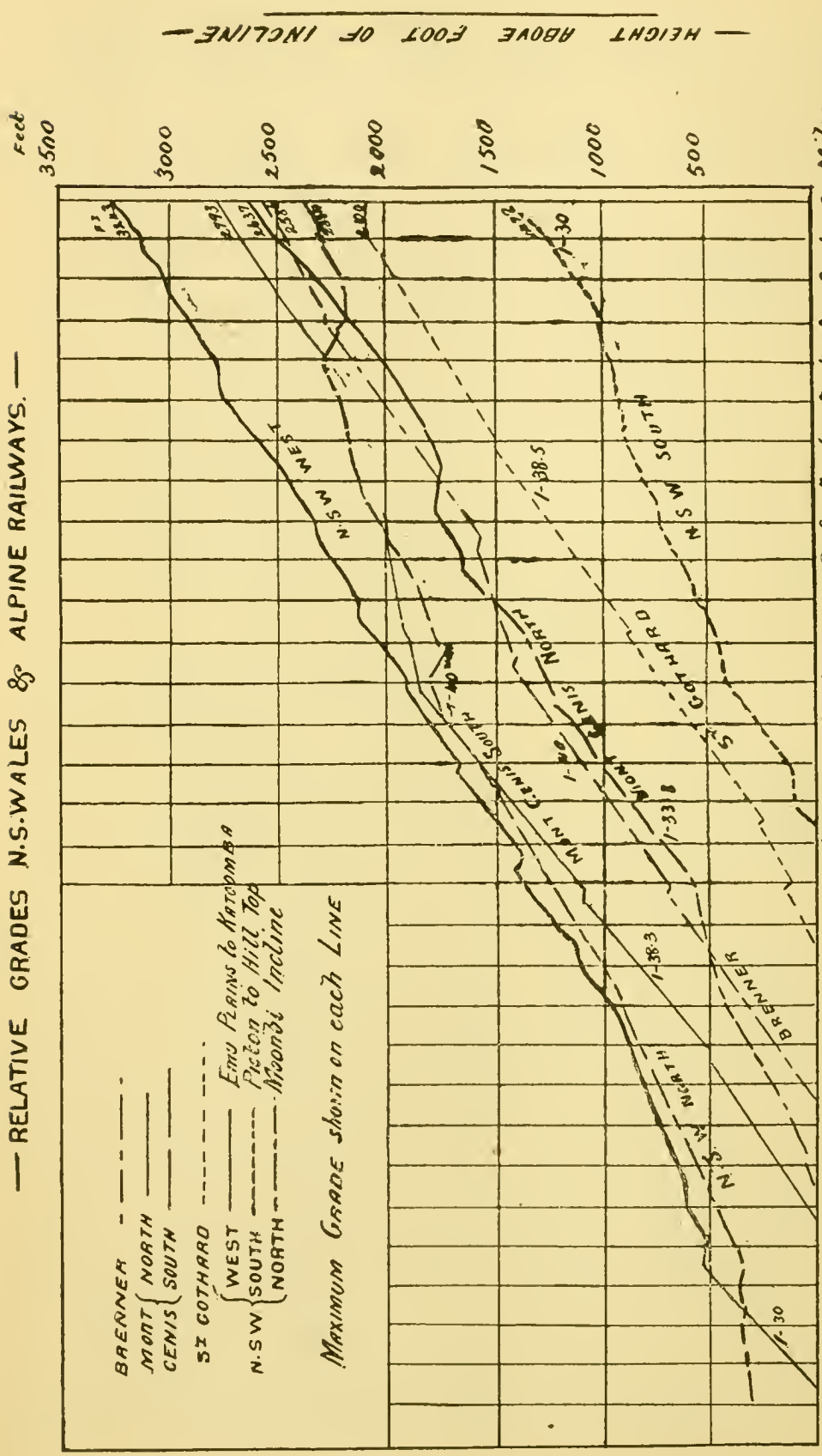
Gradient.	As originally constructed.		Total.		As improved by deviations.		Total.	
	Miles.	Chains.	Miles.	Chains.	Miles.	Chains.	Miles.	Chains.
1 in 30 to 1 in 33.....	25	20	....	....	24	54	189	79
1 in 34 to 1 in 40.....	166	25	190	45	165	25	373	8
1 in 41 to 1 in 50.....	183	60	374	25	183	9	482	14
1 in 51 to 1 in 60.....	112	12	486	37	109	6	628	74
1 in 61 to 1 in 75.....	144	59	631	16	146	60		
	631	16			628	74		

The Great Western line, for instance, is more difficult to work than any of the Alpine railways, the ruling grade (see Fig. 1), radius of curve and frequent loss of elevation which has to be regained being all against the railways of this colony. The following table will illustrate clearly the various lines in question :

Railway.	Length of incline. Miles.	Rise. Feet.	Maximum grade, ascending.	Sharpest curve. Chains.
Brenner.....	22.25	2 586	1 in 40	14.16
Mont Cenis, North.....	24.75	2 637	1 in 33	17.
Mont Cenis, South.....	25.25	2 793	1 in 33	24.
St. Gothard.....	18.5	2 100	1 in 38	14.50
New South Wales, West.....	29.5	3 248	1 in 30	8.
" " South.....	15.5	1 477	1 in 30	16.
" " North.....	30.	2 105	1 in 40	12.

Lurching is principally caused by the fact that it is necessary to work up the superelevation of the outer rail on the straight portion of the road before the curve is reached; consequently, the wheels slide down to the low side, and the flanges rub hard on the low rail immediately before entering the curve, and in taking the curve the flange on the low-side leading wheels suddenly leaves the low rail, and the flange on the high side strikes the high rail, causing the carriage to lurch.

With a properly laid out transition curve the radius is infinity at the point of inflection, and decreases until at the point where it joins the circle the radius of the transition curve is equal to that of the circle; therefore the superelevation can be gradually worked up from the point of inflection, and there will be no tendency for the flanges of the leading wheels to take the low rail, as is the case when the supereleva-



Information re Alpine Railways taken from Paper by J. L. V. Harcourt, Proceedings Institute Civil Engrs Vol XCV.

Fig 1.

tion is worked up on the straight, and, consequently, there is no sudden lurch. The practical application is very simple, and the following example may be sufficient to explain the matter.

For instance, take two reverse curves of 8-chain radius with two chains of straight between them; to construct the transition curve, all that is necessary is to lay off parallel tangents at a distance of one-third the offset at one chain, that is, 16½ ins., and from the parallel tangent set out the 8-chain curves in the ordinary way, then the transition curve will meet the circle at a point one chain from the tangent points and will pass midway between the original and the new tangent points, and the origin of the curve will be one chain back from the tangent point.

It will be seen in the above example that the only extra work involved is to set out the curve 16½ ins. inside the ordinary curve where no transition curve is introduced.

One question that deserves attention is the easing changes of grade by vertical curves; where the changes of grades are not properly eased off, the risk of breaking couplings is very great, especially the case where there is an abrupt change from a falling to a rising grade.

Permanent Way.—The standard rail for the New South Wales railways is an 80 lbs. to the yard steel rail, and at present no less than 200 miles exist. The sleepers are laid 2 ft. 7 ins. center to center, each sleeper averaging in weight over 2 cwt. 1 qr. The lightest rails are 71-lb. steel rails, but much of the road is 75-lb. iron and steel, and 80-lb. steel rails. The question of the weight of a rail, however, is rather one of economy than security, as the 71-lb. steel rail is sufficiently strong to carry an engine weighing considerably over 58 tons.

A table is given on the following page showing the weight of engines run upon those rails and the weight of rails in use in other parts of the world, together with some particulars of the weight borne by some of the driving wheels.

At the Annual Convention of Master Mechanics and Locomotive Superintendents, held in 1891, a committee of the Society reported that the limit of weight per driving axle should be 14½ tons for rails under 60 lbs., and 16 tons 1 cwt. for rails over that weight.

The Lancashire and Yorkshire Company have running upon their lines about 300 engines, with a weight upon a pair of driving wheels of from 15 tons 10 cwt. 1 qr. to 17½ tons; the Great Western of England

Railway.	Total weight in working order.				Maximum weight on one axle.		Weight of rails per yard.		Weight of steel rails per yard per ton on each wheel.		Authority for weights of engines.
	Engine.		Engine and Tender.				Iron.	Steel.	Lightest rail.	Heaviest rail.	
	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.	Lbs.	Lbs.	Lbs.	Lbs.	
Central New Jersey	55	6	.....		19	14	56 and 65	62 and 70	6	7	"R. R. Gazette," 12-2-92.
Baltimore and Ohio	59	8	93	6	15	14	60 and 80	67	$8\frac{1}{2}$	$8\frac{1}{2}$	" " Nov. 27th, 1891.
New York Central	57	1	89	6	17	16	none	66 to 80	$7\frac{1}{2}$	$9\frac{1}{2}$	" " 13-9-91.
Philadelphia and Reading	50	0	.....		17		none	56 to 90	6	10	" " Nov. 13th, 1891.
St. Louis	58	13	92	19	15	6	.....	67	8	8	" " 1-1-92.
Erie	58	0	92		15		.....	56 to 65	7.4	8.7	" " 13-6-90.
Atchison and Topeka	58	0	.....		15	9	.....	56 to 65	7	8	" " 15-8-90.
Chesapeake and Ohio	59	5	.....		15	6	.....	56 to 75	7.3	9.8	"R. R. Journal," July, 1890.
Master Mechanics	59	8	.....		14	18	.....	.....	.....	.....	" " 8-1 92.
L. & N. W. Railway	52	0	77	2	15	10	.....	84 to 90	$10\frac{1}{2}$	$11\frac{1}{2}$	"Engineering," Nov. 13th, 1891.
North Eastern	46	13	86	13	17	15	.....	90	.....	10	"R. R. Journal," May, 1890.
Great Northern	45	3	78	11	17		.....	82	.....	$9\frac{1}{2}$	"Engineering," May 20th, 1890.
N. S. W., 10-wheel Baldwins	58	7	90	6	15	5	75	71 to 80	$9\frac{1}{2}$	10.4	
Eastern, of France	54	18	97	1	16	2	.....	69 to 89	$8\frac{1}{2}$	11	"Engineer," March 4th, 1892.

carry 15½ tons to 16½ tons on a pair of wheels; the Midland Railway Company carry 17½ tons on the driving axle of an express engine. It is a practice in America to run engines with as great a weight as 17 tons to 19 tons on one axle, at high speeds, on rails varying in weight from 56 lbs. to 70 lbs.

The Spacing of Sleepers.—In dealing with this question it must be borne in mind that it is not determined solely by questions of strength, but by the fact that a sufficient bearing area must be obtained for the rail on the sleeper for the class of wood used, and for the sleeper on the ballast. With the soft woods in use in Europe and America, it is absolutely necessary that the bearing surface of the rail and sleeper should be large enough to prevent the rail cutting into the sleepers. In England this is guarded against by using cast-iron chairs, and in America by placing the sleepers closer together. Even with this precaution, continual trouble is experienced in consequence of the rails and chairs cutting into the soft woods, which involves constant attention to prevent the rails from becoming loose.

The iron bark sleepers we possess in this colony are so hard and durable that the fastenings retain their hold exceedingly well for years, and the rail cuts but slightly into the timber.

A very important matter to be considered in connection with the permanent way is the weight of the road, as compared with that of the rolling stock passing over it, as the weight of the road as a whole measures its resistance to the blows of traffic. The following statement shows the weight of 1 mile of permanent way of the three types of road in this colony, compared with the standard main line of a leading railway company in England.

Weight of 1 mile of permanent way.		Tons.	Hundredweights.	Quarters.
New South Wales Railways.....	75-lb. D. H. iron rails laid in 27-lb. cast-iron chairs upon iron bark sleepers 9 ft. long by 10 ins. wide, by 5 ins. thick, 3 ft. apart centers.	384	7	3
	71½-lb. T steel rails laid upon iron bark sleepers 8 ft. long by 9 ins. by 4½ ins., 2 ft. 7½ ins. centers.....	282	2	2
	71½-lb. T steel rails laid upon iron bark sleepers 9 ft. long by 10 ins. by 5 ins., 2 ft. 7½ ins. centers.....	346	8	1
	80-lb. T steel rails laid on iron bark sleepers 9 ft. by 10 ins. by 5 ins., 2 ft. 7 ins. centers..	371	1	3
English, London and North Western	84-lb. bull-headed rails laid in 45-lb. cast-iron chairs upon creosoted Baltic sleepers 9 ft. by 10 ins. by 5 ins., 3 ft. apart centers.....	341	1	1

The weight of the standard Baltic timber in use on the leading lines in England, 9 ft. long by 10 ins. by 5 ins., creosoted, is 160 lbs., and in this colony that of the iron bark sleepers of similar dimensions is 252 lbs. As regards the durability, the life of the iron bark sleeper is fully double that of the Baltic sleeper.

In this colony's railways the rails are generally laid on sleepers placed 2 ft. 7 ins. to 2 ft. 8 ins., center to center, on the straight; and in sharp curves of less than 15 chains radius, sleepers are placed as close as 2 ft. 4 ins., center to center, and in curves from 15 to 30 chains radius, 2 ft. 9 ins., center to center. It is well known to engineers that the spacing of sleepers plays the most important part in the stability of a railway.

From the "Encyclopædia Britannica" of 1886 the following facts from articles written by D. K. Clark, C. E.; Professor A. T. Hardy and A. M. Wellington, C. E., are extracted:

In the United States the Vignoles rails are universally used for railways. No railways with any considerable traffic are now laid down with less than 60 lbs. per yard. The Pennsylvania railway, laid to a gauge of 4 ft. 9 ins., is constructed of flange rails, in lengths of 30 ft. Allowance for expansion, when rails are laid in winter, is provided by laying the rails $\frac{5}{16}$ in. apart, endwise; in summer a space of only $\frac{1}{16}$ in. in width is allowed. The cross-sleepers are 8 ins. wide by 7 ins. deep by 8½ ft. in length; they are laid so closely that the maximum distance apart between the centers does not exceed 2 ft. There are 16 sleepers for each length of 30 ft., and the sleepers at the joints are laid with a clearance of over 10 ins. between them. The rails are fastened with spikes to the sleepers at the inside and outside. The width of the double line of way at the formation level is 31 ft. 4 ins. in cuttings, and on embankments the width of formation is 24 ft. 2 ins., sloping from the center at the rate of 1 in 20. The ballast is laid to a depth of not less than 12 ins. under the sleepers, and is filled into the level of the upper surface of the sleepers. Where stone ballast is used it is often broken to a uniform gauge of 2½ ins. For double lines, large stones are placed in the bottom at the center between the lines, to allow for drainage.

The sleepers (in America called ties or cross-ties) are usually of white oak, hewn on top and bottom with the natural surface of the tree on the sides. The usual dimensions are 6 to 7 ins. thick; 8, 8½ to 9 ft. long; and 8 to 10 ins., or even 12 ins., face. The usual rule is to place them 2 ft. or less apart, and 2 640 to 2 700 to the mile. The large bearing surface thus afforded has especially favored the use of the flat-based or Vignoles rail, and it is in exclusive use throughout

North, and for the most part of South, America. The rails now most largely rolled weigh from 56 to 65 lbs. per yard. In the north and east rails of 70, 72, 75 and 80 lbs. sections are in limited but increasing use. The close propinquity of sleepers gives much greater stiffness to the rail than comparative weight alone would indicate, a 60-lb. rail being fully equivalent in stiffness and strength to an 80-lb. rail, supported on chairs 3 ft. between centers.

From the above it will be seen, though the rail is lighter, the spacing of the sleepers makes the road equal to the New South Wales standard 80-lb. rail with sleepers spaced 3 ft. apart.

For comparison, it may be stated that Belgium has about 3 250 miles of railway, of which about 2 000 miles are owned and operated by the State. The standard rails of flange section, 29 ft. 6 ins. long, weigh about 104 lbs. per yard. They are fastened to the ties by screw spikes, while ordinary spikes are used for the lighter rails. The rails are laid with square, suspended joints, spliced by heavy angle bars, 2 ft. 3 ins. long, with four bolts, the angles being fastened to the ties by screw spikes, and on all ties and tie plates. There are 12 ties to a rail length, spaced 2 ft. at the joints, and 2 ft. 4 ins. to 2 ft. 8 ins. intermediate.

In New South Wales railways the ballast is laid to a depth of 12 to 15 ins., and no less than 700 000 tons of ballast have been used; out of that quantity 600 000 tons have been blue metal, hard quartz or slag. In regard to the ordinary repairs to the permanent way, it may be mentioned that for relaying alone there has been paid during the last three and a half years the sum of £230 000.

Owing to the introduction of heavier rolling stock to meet modern requirements, it has been found necessary by all the large railway companies throughout the world to strengthen the permanent way on their busier lines. Heavier rails are being introduced, and sleepers are closer spaced ; and this is not done in the interests of safety alone, but also on economical grounds, as on many lines the existing permanent way was sufficiently strong to carry the increased weights at the greater speed now aimed at.

From the New South Wales *Railway Budget* the table on the following page giving some particulars of the heavier rails recently adopted on the several lines is extracted:

Railways.	Dimensions and Weight of Rails.							Sleepers.	
	A, Height of rail.	B, Width of bottom (flat).	Width of webb.	Proportion B. ÷ A.	Weight per yard	Length of rail.	Thickness of webb.	Number per pair of rails.	Average distance between sleepers.
	Inches.	Inches.	Inches.	Percentage.	Pounds.	Feet.	Inches.		Inches.
Austrian State Railways, 1891	5.344	4.716	2.358	88.3	86½	32¾	0.707	13	30.261
						45¼	.....	19	31.047
Prussian State Railways, 1885	5.266	4.126	2.279	78.4	67	29½	0.432	10	35.37
" " " 1891	5.423	4.323	2.829	79.7	90	29½	0.55	11	32.147
Gothard Railway	5.698	5.109	2.751	89.7	93¼	39½	0.571	15	31.44
								16	29.475
Paris-Lyon-Mediterranean	5.580	5.109	2.593	91.6	94½	39½	0.55	15	31.44
								16	29.475
Philadelphia and Reading	4.991	4.991	2.868	100	90	39½	0.668	15	31.44
								16	29.475
New South Wales	4.907	5	2.5	1.019	80	30	0.812	11	

From the latest statistical information available it appears that there are about 383 600 miles of railways in operation throughout the world. Of these 207 144, or 54.1%, are in America; 138 000, or 35.9%, in Europe; 21 100, or 5.5%, in Asia; 11 984, or 3.1%, in Australia; and 5 372, or 1.4%, in Africa. The mileage of the United States, viz., 166 410 miles, is greater than that of the whole of Europe.

If the five leading European countries are taken, they stand thus in regards to mileage : Germany, 26 623 miles; France, 24 157 miles; the United Kingdom, 20 090 miles; Russia, 19 251 miles; and Austro-Hungary, 16 837 miles.

If the ratio of mileage to the number of inhabitants is taken, the countries rank differently. France comes first, with 6.2 miles for each 10 000 inhabitants; Germany second, with 5.6; the United Kingdom third, with 5.2; Austro-Hungary and Russia, fourth and fifth, with 4.1 and 2.0 respectively.

The Australian Colonies show far higher mileages; for instance, in Queensland we have 56.6 miles for every 10 000 inhabitants; South Australia follows with 52 miles; then New Zealand with 28.3; Victoria with 25.2; and New South Wales, 20 miles.

Considering the number of persons per mile of line, the figures are: France, 1 582; Germany, 1 706; the United Kingdom, 1 913; Austro-Hungary, 2 434; Russia, 4 987; Queensland, 176; South Australia, 196; New Zealand, 358; Victoria, 399; and New South Wales, 501.

In the above comparisons the United Kingdom ranks third among the European States; but it must not be overlooked that the size of the country and the density of population are important factors in railway matters. If these be taken into consideration the United Kingdom ranks first with 318 persons and 0.17 mile of line per square mile; Germany takes second place with 225 persons and 0.13 mile; then follows France with 187 persons and 0.12 mile; Austro-Hungary with 155 persons and 0.07 mile; and, lastly, Russia with 46 persons and 0.01 mile of line per square mile.

The table on the following page gives detailed information respecting railway mileage, population, miles of line per 10 000 inhabitants, and the number of persons to each mile of railway.

Rolling Stock.—In the development of railways the design of rolling stock has gone through various stages, and in early days a very wide latitude was given for experiments, more especially in America,

Countries.	Miles of Railway.	Population.	Miles of railway per 10 000 inhabitants.	Persons per line of mile.
Europe.				
Germany	26 623	46 875 705	5.6	1 706
France	24 157	38 218 903	6.3	1 582
The United Kingdom	20 090	38 443 295	5.2	1 913
Russia	19 251	96 009 247	2.0	4 987
Austro-Hungary	16 837	40 986 000	4.1	2 434
Italy	8 112	30 947 306	2.6	3 813
Spain	7 452	17 550 246	4.2	2 355
Norway and Sweden	2 503	6 752 800	3.7	2 698
Belgium	2 263	6 093 798	3.7	2 693
Switzerland	1 875	2 934 057	6.4	1 565
Denmark	1 203	2 172 705	5.5	1 805
Other European States	7 634	22 907 438	3.3	3 001
Total	138 000	349 873 000	3.9	2 536
America.				
United States	166 410	62 875 956	26.4	378
Canada	15 000	5 075 855	29.6	338
Argentine Republic	5 427	4 086 492	13.3	750
Remaining States	20 307	49 296 697	4.2	2 427
Total	207 144	121 335 000	17.1	585
Australia.				
New South Wales	2 359	1 182 500	20	501
Victoria	2 903	1 159 729	25.2	399
Queensland	2 320	410 330	56.6	176
New Zealand	1 869	668 651	28.3	358
South Australia	1 660	325 723	52	196
Western Australia	499	49 835	124.7	100
Tasmania	370	146 667	26.7	393
Total	11 984	3 943 435	30.5	329
Asia.				
India	17 564	210 754 000	0.83	12 000
Japan	1 428	39 607 000	0.36	27 736
Russian Transcaspian	901	7 284 000	1.12	8 085
Dutch Colonies	814	22 820 000	0.36	28 034
Ceylon	192	3 000 000	0.64	15 625
China	124	404 180 000	0.003	3 259 506
All other countries	77	142 954 000	0.005	1 856 546
Total	21 100	830 599 000	0.254	39 364
Africa.				
Algeria and Tunis	1 925	5 317 000	3.7	2 762
Cape Colony	1 863	1 524 000	12.3	818
Egypt	960	6 806 000	1.5	7 090
Natal	376	530 000	7.1	1 409
Mauritius	92	372 000	2.4	4 044
All other countries	156	188 772 000	0.09	1 210 076
Total	5 372	203 321 000	0.27	37 849
Grand total	383 600	1 509 071 435	2.5	3 943

where patents for every possible contrivance were taken out; but at the present time a very strong tendency has set in to reduce every thing to a standard, and although the Americans are keenly alive to all improvements, yet, as far as possible, it is attempted to reduce every detail down to a standard form. Nor is this tendency confined to America, as for many years past the large railway companies of England have been concentrating their attention in the same direction.

A very interesting series of standard types of locomotives and carriages has been developed on the London, Brighton and South Coast Railway. The whole of the rolling stock on these lines has been constructed in the company's workshops to their own templates, thus enabling all repairs and renewals to be rapidly and economically carried out. The carriages of this line are of a very neat pattern, being built to a uniform design, and have a very good appearance. The central buffer and draw gear of the carriages on the London and Metropolitan Railway are very ingenious and enable the train to pass round sharp curves with great ease. The London and North Western Railway has also carried out the system of building their rolling-stock to a uniform pattern. This company, too, manufactures the whole of their stock in their own workshops.

In England the individual railway companies have adopted standards of their own, yet the standards of no two companies agree; for instance, each of three of the leading companies running from London has its own type of engines and carriages, and although each has the same class of traffic to deal with, it has engines of entirely different types in use.

On the Midland Railway the express traffic has been worked with four coupled engines with wheels 7ft. in diameter, cylinders 18 ins. diameter and 26-in. stroke, with a four-wheeled bogie in front. On the Great Northern Railway, the engines used for fast traffic have driving wheels 8 ft. in diameter, outside cylinders 18 ins. and 28 ins. stroke. On the London and North Western Railway, the express traffic was worked with four coupled engines, with inside cylinders 17 ins. diameter, with 24-in. stroke and 5 ft. 6-in. wheels.

In regard to locomotives, a long article might be devoted to the comparison of the practice of the various countries. In America there are a number of distinct types, classed according to the number and arrangement of the wheels, but with special features of design

and detail introduced by the builders. There is a great diversity of types of engines in England. Tank engines, usually with side tanks, are generally used for the suburban traffic in England and New South Wales; while for the same class in America, engines have generally a tank at the frame. In England the various companies have in a more or less perfect way adopted standards of their own, but the tendency of American practice is to adopt a far more general system of standards; for the vast extent of railways in America, owned by a large number of different companies, having an enormous traffic necessitating the stock of one company traveling over the lines of other companies, it is evident that if the various details of car or wagon stock could all be made to the one system of standards, any repairs that might be necessary to the stock of one company could be quickly executed.

In New South Wales there are 28 recognized types of engines, including all the new American and English engines, and a total stock existing at present of 481 engines; 331 of these belong to four types. Some of the engines have been manufactured in the Colony, and the others have been imported from the following firms, viz.: Dubbs & Co., Glasgow; Manning, Wardle & Co., Newcastle-on-Tyne; Beyer, Peacock & Co., Manchester, and Burnham, Parry, Williams & Co., Baldwin Locomotive Works, Philadelphia, U. S. A.

With regard to the height of the center of the boiler the express engines of this colony are lower than a good many express engines. For example, on the Central of New Jersey, an express engine running at extremely high speed, is 9 ins. higher than the Baldwin engines of New South Wales; the Baltimore and Ohio engine is 1½ ins. higher; the New York Central engine, which runs the Empire State Express, one of the fastest trains in the world, and going around numerous curves, is 10½ ins. higher. Cleveland, Cincinnati, Chicago and St. Louis express trains are the same as in this colony.

The North Eastern Railway in England express engine is 2 ins. higher, and one of the engines is 1 in. lower. The Great Northern standard express engines, which have for many years run about the fastest trains in England, are 5¾ ins. lower, but the wheel is 3 ft. greater in diameter.

Of course, the vital thing in these matters is the height of the center of gravity above the rails, and it is found, by approximate calculations, that the Great Northern express engine is about 3 ins. higher

in the center of gravity than the Baldwin engines running in this colony; therefore, the writer thinks that the center of gravity of engines in use in this country is perfectly safe, that is to say, the 10-wheeled locomotives have a lower center of gravity than any of the English or American engines just quoted.

The table of figures on the following page is submitted.

The general dimensions of the 10-wheeled Baldwin engine in use in this colony are as follows:

Diameter of cylinder	21 ins.
Stroke of piston	24 "
Diameter of drivers	61 "
Area of fire grate	27.7 sq. ft.
Area of heating surface in firebox (copper)	105.6 "
Area of heating surface in fire tubes (brass)	1 822.5 "
Total	1 928.1
Tractive force per pound of M. E. P. per square inch	171 lbs.
Maximum boiler pressure	160 "

Total weight of engine in running order, with two-third glass of cold water and sandboxes full:

	Tons.	Cwts.	Qrs.
Weight on driving wheels	43	11	0
Weight on bogie wheels	14	16	0
Total weight of engine	58	7	0

	Tons.	Cwts.	Qrs.			
Weight of tender, empty	13	12	0			
Weight of 3 000 galls. water.	13	8	0			
Weight of 5 tons coal	5	0	0			
				32	0	0
Maximum weight in running order of engine and tender				90	7	0

The general dimensions of the 30 new 10-wheeled express locomotives built by Messrs. Beyer, Peacock & Co., of Manchester, England, and now running on the New South Wales Railways, are as follows:

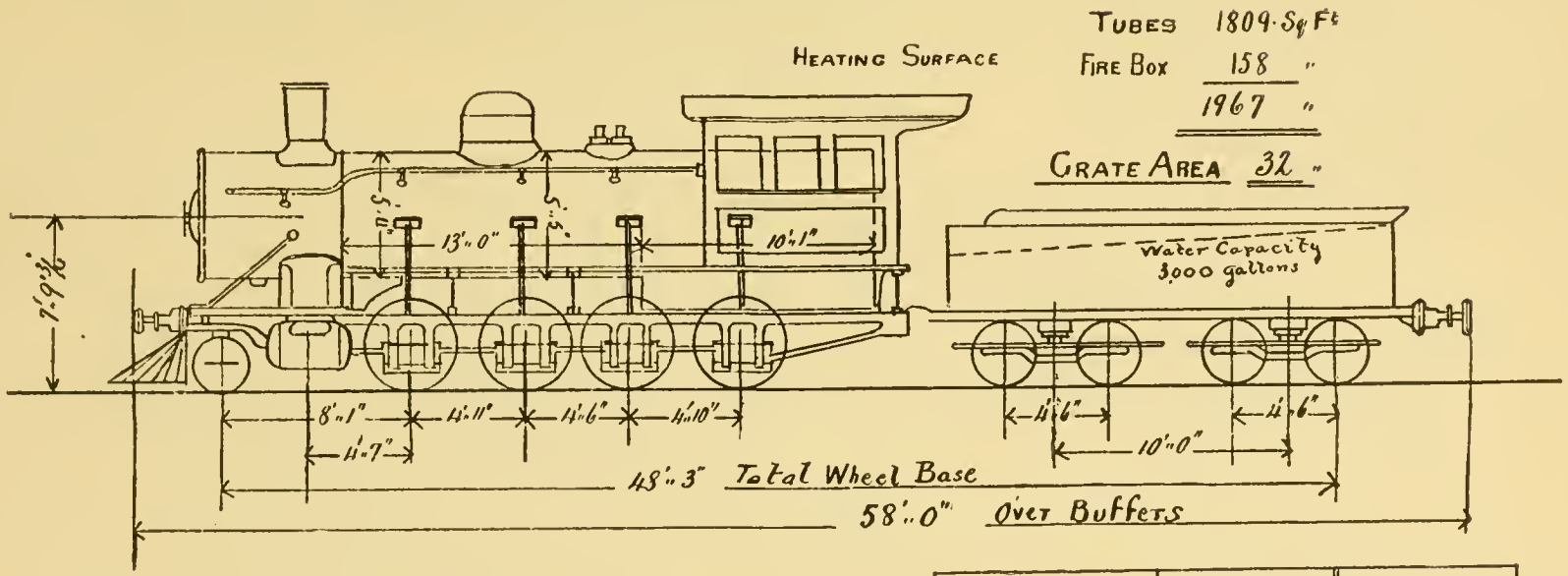
Cylinders, diameter	20 ins.
Stroke of piston	26 "
Number of coupled wheels	6
Diameter of coupled wheels	5 ft.
Diameter of bogie wheels	3 " 3 ins.
Heating surface—Firebox	130 sq. ft.
Tubes	1 786 "
Total	1 916 "
Grate area	27 "
Boiler pressure	160 lbs.

Heights of Center of Boiler, Gravity, Etc., Various Express Locomotives.

Railways.	Number of wheels coupled.	Center of boiler above rail.		Diameter of wheels.				Diameter of boiler.	Weight of engine in working order.		Center of gravity above rail.	Firebox above or between frames.	Remarks.
				Driving.		Bogie.							
		Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Inches.	Tons.	Cwts.	Feet.		
Central of New Jersey	4	8	6	5	8	3	0	58	55	6	5.13	above	Runs regularly of 70 miles an hour.
Baltimore and Ohio	6	7	10½	5	2	2	6¼	64	59	8	4.60	between.	
New York Central	4	8	7½	6	6	3	0	58	57	1	5.24	above	Runs fastest train in world.
Philadelphia and Reading	4	8	9	6	6	4	0	57½	50	0	5.22	above	Runs regularly over 70 miles an hour.
Cleveland, Cincinnati, Chicago and St. Louis	6	7	9	5	6	2	6	60	58	13	.....	between.	
Erie	6	8	5½	5	8	2	9	60	58		.....	above.	
North Eastern	2	7	11	7	7¼	3 4 trailing.	7¼ 7¼	51	46	13	5.03	between.	Attained highest speed, 86 miles an hour, ever made in England.
North Eastern	4	7	8	6	8¼	3	7¼	57½	about 47	10	4.79	between.	Runs fast trains on lines over sharp curves.
Great Northern	2	7	3¼	8	1½	3	11	50	45	3	4.79	between.	Has run very fast trains in England for years.
New South Wales	6	7	9	5	1	2	6	62	58	0	4.52	between.	
New South Wales	6	7	8	5	0½	.....		58	56	15	.....	between.	

Note.—The New South Wales 10-wheelers have, therefore, a lower center of gravity than any of the above English and American engines, though the latter engines run the fastest trains in the world.

— CONSOLIDATION GOODS BUILT BY THE BALDWIN C^{o}/$_{y}$ —



NOTE: The Two middle pairs of Coupled Wheels are Flangeless

— Cylinders 21" x 26" Stroke —

Total weight on 4 sets of driving wheels when loaded 56. 15. 3

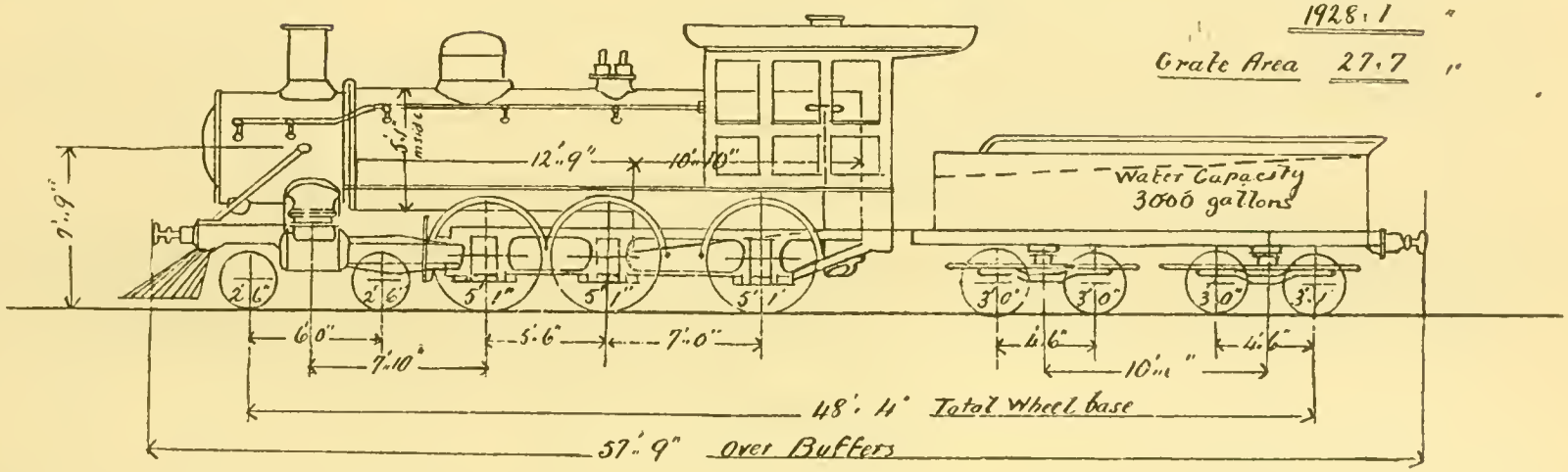
	Empty	Running Order
	T. C. Q.	T. C. Q.
Weight Engine	55 . 15 . 3	62 . 12 . 2
" Tender	13 . 12 . 0	32 . 0 . 0
" Total	69 . 7 . 3	94 . 12 . 2

FIG 2.

— 10 WHEELED EXPRESS :— BUILT BY THE BALDWIN COY —

Heating Surface

Tubes 1822.5 sq Ft
Fire Box 105.6 "
1928.1 "
Grate Area 27.7 "



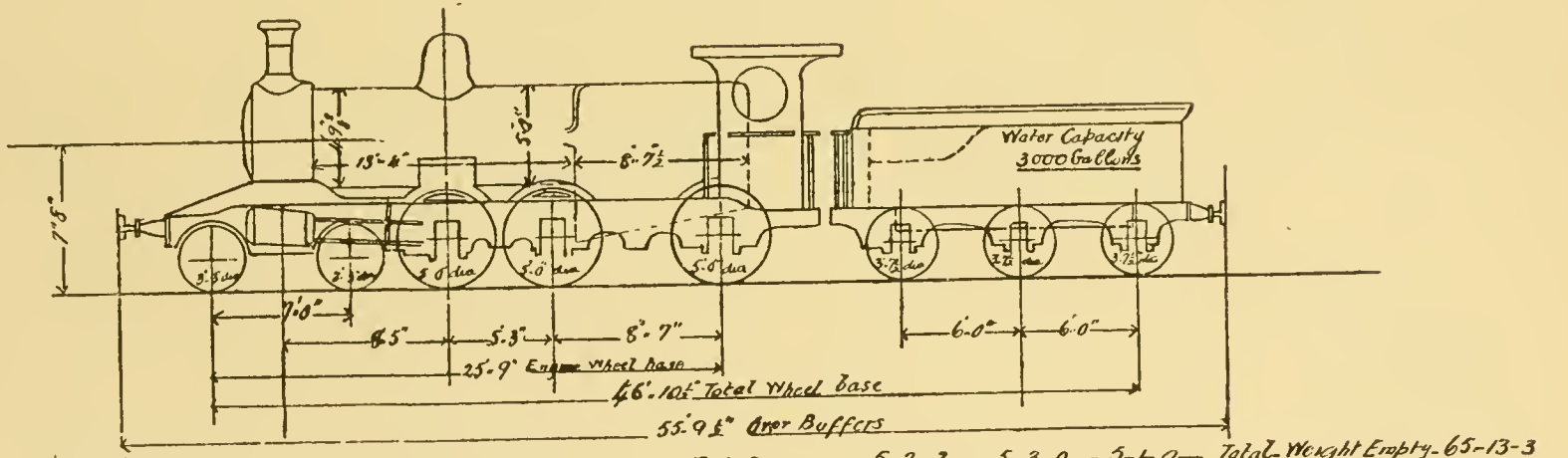
Note: The Centre Pair of Coupled Wheels Are Flangeless

Cylinders 21" x 24" Stroke

Total Weight on 3 sets of driving wheels when loaded 43.11.0 (T C Q)

	EMPTY	Running Order
	T C Q	T C Q
Weight Engine	51.5.0	58.7.2
" Tender	13.12.0	32.0.0
" Total	64.17.0	90.7.2

FIG. 3.



10 WHEELED (ENGLISH) EXPRESS BUILT BY BEYER PEACOCK & Co

FIG. 4.

	Tons.	Cwts.	Qrs.	
Engine—Weight empty.....	50	7	0	
In steam.....	56	10	3	
Tender—Coal capacity.....	4	10	0	
Water capacity.....				3 000 galls.
Weight, loaded....	31	16	1	
Weight, empty....	15	6	3	

Total weight of engine and tender in working order.....	Tons.	Cwts.	Qrs.
	88	7	0

Consumption of fuel, 42 to 44 lbs. per mile.

All the engines are fitted with the most modern improvements, such as the Westinghouse automatic brake applied to engine, tender and carriage wheels; sight-feed lubricators for lubricating the cylinders and side valves, and two of Gresham & Craven's improved injectors, Nos. 8 and 9, for feeding the boilers. The boilers are made of steel, having fireboxes of the Belpaire pattern and brass tubes.

Mr. Lentz, Locomotive Engineer of the Government Railways, Germany, read an interesting paper on "The World's Locomotives," at a meeting of the German Engineering Association held last year.

He gave the total number of locomotives running on the earth's surface as about 109 000, divided as follows: Europe, 63 000; America, 40 000; Australia, 2 000; Asia, 3 000, and Africa, 700.

In Europe, Great Britain and Ireland possess 17 000 engines; Germany, 15 000; France, 11 000; Austro-Hungary, 5 000; Italy, 4 000; Russia, 3 500; Belgium, 2 000; the Netherlands and Spain, 1 000 each; Switzerland, 900; and the remaining countries, 2 600.

In America the United States heads the list with 35 000 engines; Canada follows with 2 000; and the remaining States claim 3 000.

In Asia, British India claims 2 500 engines, and the other countries 800.

In Australia, New South Wales possesses 481 engines; Victoria, 462; Queensland, 255; South Australia, 241; Tasmania, 52; New Zealand, 266; and Western Australia, 24.

Railway Carriages.—In America there is a large amount of money and skill employed in the construction, equipment and decoration of cars. One feature about them is the comfort, convenience, luxury and artistic finish. In England, dining cars have been introduced, but the lack of communication with the rest of the train is a drawback to their use. Drawing-room, saloon, sleeping and other such cars are also

used in England. Many of the modern carriages are carried on four or six wheel trucks instead of upon the older system of rigid axles. Some of them are fitted with lavatory accommodation, but the arrangements are crude, and they are not properly looked after. In New South Wales, there are various types of railway carriages used, viz., the sleeping cars, Pullman cars, American, Ashbury, lavatory, express and other cars. All these are principally manufactured by firms of New South Wales, and any repairs or alterations, etc., are carried out in the Government workshops. One feature about them is the comfort, convenience, luxury and artistic finish.

A brief description of some of the various types of cars in use is added:

Type.	Description.
Redfern	A double bogie carriage on eight wheels, the body made in six compartments.
Cleminson	Same as the Redfern in every respect, excepting the bogie, in which a slight difference is made in construction.
American	Long car, American platform, promenade through the center; bogie same as the Cleminson.
Ashbury	Carriage with two Ashbury bogies (six wheels), and divided into first and second class compartments.
Eight-wheel Radial	Built after the Redfern type in body. Bogies substituted by four pair of wheels at equal distances apart.
Six-wheel Radial	A carriage with six compartments and three pair of wheels, one pair under each end and one pair under center of carriage.
Four-wheel	Small carriage with three and four compartments and two pair of wheels.
Lavatory	Double bogie carriage, six compartments, on eight wheels, with lavatory inside.
Express	Same build as lavatory carriages, but contains no lavatory compartments.
Ordinary	A carriage resembling the Redfern type in construction, but have two ordinary or common bogies of eight wheels.

Each of the above types can either be a first-class, second-class or composite carriage.

In New South Wales the Westinghouse automatic brake is universally used on passenger trains.

Speed.—In the matter of average speed, it must be admitted that the ordinary express trains on English railways make better time than the same kind of trains on Australian and American railways. The *Central European Railway Gazette* publishes a tabulated statement showing the total daily mileage and average speed per hour of express trains running over the railways of several continental countries. The express trains of the Prussian Government Railway head the list of average speed with 30.944 miles per hour, which, however, is .076 mile less than obtains in New South Wales. Belgium, with its almost level lines, shows the lowest average with 29.565 miles. This is, however, only 3.685 miles in advance of the average speed of our mail trains, which have to climb steep grades and are also delayed by frequent stoppages.

Country.	Total daily mileage.	Time occupied.		Average speed per hour, inclusive of stoppage.
		Hours.	Mins.	Miles.
France	52 783.3	1 758	15	30.013
North Germany	28 703.8	931	7	30.821
Prussian Government Lines	27 588.1	890	53	30.944
The Netherlands	9 107.8	296	7	30.758
Belgium	6 781.3	228	25	29.565
New South Wales	976	31	28	31.02
N. S. W. Mail Trains	2 506	96	49	25.88

The new 10-wheeled express locomotives built by Messrs. Beyer, Peacock & Co., of Manchester, for the New South Wales railways are employed in working the express and mail trains over the southern, western and northern lines, their running being confined to the difficult portions of the road, such as from Sydney to Junee, on the south (286 miles); Sydney to Dubbo, on the west (278 miles), and Sydney to Newcastle, and Singleton to Jennings, on the north (446 miles). Their load over the 1 in 30 grades is 165 tons, and in the 1 in 40 grades 205 tons; and in a recent trial one of these engines hauled a train weighing 225½ tons behind the tender up a grade of 1 in 42 at a settled speed of 20.45 miles per hour, developing 1 080 H. P.

To give some idea of the speed at which these trains are regularly running, the Melbourne express train, which weighs 115 to 205 tons, is scheduled to travel over the section Sydney to Junee and return at an average speed of 34.6 miles per hour, exclusive of stoppages, and the train has to be lifted through an accumulated vertical distance of more than 8 000 ft. over rising grades on the down journey alone.

In the following table will be found the speeds of the Baldwin engines, obtained from five trips made, the train being made up of Pullman sleeping cars and first-class lavatory carriages:

No. of Trip.	Gradient.	Mean speed on the whole length of gradient.	Weight of train, exclusive of engine and tender.		Remarks.
		Miles per hour.	Tons.	Cwts.	
1..	1-40	18.50	179	5	Length of gradient, 2½ miles.
2..	1-40	20.15	157	12	Several curves 16 chains radius on first mile.
5..	1-40	21.09	157	12	About 2 miles 1-30 and ¾ mile.
3..	1-30	18.87	121	14	Of 1-33, curvature moderate.
4..	1-30	15.17	144	2	

An interesting return has been published by the Board of Trade of the fast trains running on week days between London and Birmingham, Bradford, Hull, Brighton, Bristol, Derby, Leeds, Leicester, Norwich, Liverpool, Manchester, Newcaste-on-Tyne, Nottingham, Portsmouth and Sheffield, giving in each case the alternative lines of railway, with the distance, the average time occupied on the journey, and the average rate of speed per hour on both up and down journeys. From the details there given, the following figures are extracted, showing the average speed per hour by the fastest trains on each route down from London and up to London :

Between London and—	Railway.	Down.	Up.
Birmingham	Great Western	45	44
"	London and North Western	45½	45¾
Manchester	Midland, via Leicester	45.2	45.4
"	Midland, via Kettering and Nottingham	47	
"	London and North Western	46¾	47
"	Great Northern	47.764	47.764
Liverpool	London and North Western	43½	45
"	Midland	45.2	46
"	Great Northern	43.468	40.629
Bradford	Great Northern	47.407	46.08
"	Midland, via Leicester	47.3	49.7
"	Midland, via Kettering and Nottingham	48.7	47.6
Leeds	Midland, via Leicester	47.9	48.8
"	Midland, via Kettering and Nottingham	49.3	49
"	Great Northern	47.974	48.391
Sheffield	Midland, via Leicester	44.8	47
"	Midland, via Kettering and Nottingham	49.3	48.8
"	Great Northern	51.157	50 625
Nottingham	Midland, via Kettering	51.6	51.7
"	Midland, via Leicester	49.7	
"	Great Northern	48	46
Bristol	Great Western	44	44
Hull	Great Northern	45.461	44.727
Newcastle-on-Tyne	Great Northern	48.683	47.130
Norwich	Great Eastern	38.3	37.3
Brighton	L. B. and S. C.	40.39	43.30
Portsmouth	London and South Western	36	37
"	L. B. and S. C.	43.29	43.29

Lighting of Railway Carriages.—At the present time the railway carriages belonging to the Government of New South Wales are lighted with gas. An iron vessel, cylindrical in shape, is placed under the floor of each car, and the pipes are laid from this to each compartment.

The question of the electric lighting of trains has received a good deal of attention on a number of railways, but, so far, the constant disadvantages of the system have been so heavy as to prevent the general adoption of electric lighting. No doubt it has great advantages in that the cars are kept much cooler and the light can be more evenly diffused. A trial has, on more than one occasion, been made on the lines of this colony, and about three years ago a sleeping car was fitted up under the direction of the Railway Commissioners by the Superintendent of Telegraphs, and made a number of journeys between Sydney and Albury, the light eliciting much appreciation; but it was found to be so costly, to work in comparison with other lighting systems, and to require such additional dead weight in the shape of accumulators, that the experiment had to be given up. Interest in the question is being revived by the proposal to light the carriages upon the South Australian lines with electricity. This experiment, however, is one that requires to be made with caution, and, judging from a recent extract from the *Railway Age*, it would appear it has been given up on other lines.

English papers announce that lighting carriages by electricity is to be abandoned in favor of compressed oil gas on the Midland Railway, as it has been found too expensive and unreliable. This company has made every endeavor for a number of years to use the electric light in its carriages, and its decision, following so soon on that of the Brighton Company, may be regarded as the *coup de grâce* of the system—at any rate for several years.

In America, in spite of many attempts, electricity is now used for lighting only in a few instances, and that for special train service. While but little definite information regarding the cost of maintenance is available from the numerous railroads that experimented in this line, the data so far received are not reassuring. The writer knows of but two instances in this country where electric train lighting has shown evidence of being a paying investment from the railroad standpoint, that is, the train could, individually, aside from any

outside traffic influence, pay all its running expenses and a fair return on the investment over and above those expenses. The systems used in these two instances are dissimilar.

As to the reliability of electricity, in no cases have the railroads that use it felt that they could dispense with the older and tried systems.

Even where the use of electricity has been fairly successful, it is very often necessary in emergencies to have recourse to oil or gas; and the results obtained on the English railways are not surprising. The use of electricity for train lighting will, however, be retarded considerably by the action of the English railways.

Sir George Findlay, General Manager of the London and North Western Railway, England, takes a different view of the present position of affairs, and instead of maintaining that the electric lighting of trains has received its *coup de grâce* through the action of English companies, he rather leans towards the idea that what has been done clearly indicates the direction in which investigations must proceed, and also that beyond doubt electricity will be the lighting medium in the future. The question is yet only in the transitional or experimental stage, and for that reason most of the companies have not attempted to adopt it on anything like a large scale.

There are at least three methods in which a current of electricity may be obtained for lighting a train. A primary battery may be used, or secondary batteries, or the dynamo may be used direct. The majority of railway engineers lean towards the secondary batteries, or the direct action of the dynamo. Probably the ultimate solution of the problem will be found in a combination of the two, or in other words, a dynamo will supply the current when the train is in motion, and the batteries, during stoppages. How the dynamo is to be driven is a question, the settling of which is not marked with the unanimous opinion of engineers, some holding that it should be carried and driven by the locomotive direct, others, that it should be driven by a separate engine, and others, that it should be driven from the axle of the guards van. But whatever method may be ultimately adopted, the writer cannot agree with the idea that electricity has received its death blow, or has even been retarded to any serious extent by the action previously mentioned, and hopes before long to see it entirely replace the oil and gas lamps at present in use.

Mr. Oswald Haes, in a paper entitled "Lighting of Railway Trains," describes the successful experiments carried out in South Australia. In his paper the author deals with the history of electricity as concerned with the lighting of trains, enumerating briefly the various systems, their faults and merits. He then deals with the system experimentally adopted by the South Australian railways. The principle upon which it was to be executed was the axle-driven dynamo, and in conjunction with accumulators, similar in every way to the one that has proved to be eminently satisfactory on the London and Brighton and several other English railways. The dynamo is of the ordinary Brush pattern, and the problem of driving from bogie axles seems satisfactorily solved when the statement is made that it has run well for upwards of four months. It is undoubtedly a very different and difficult matter to drive from bogie stock instead of fixed wheel stock, and the writer believes that the greatest difficulties have been overcome. What little trouble exists now is caused more by errors in detail than in principle, and will consequently be overcome with a little more experience. The couplings are simple, effective and economical, and are protected from interference by unauthorized persons. The system is, of course, specially adapted for trains not liable to be split up, from start to finish of a journey.

After a series of trials which have occupied the engineers for about two years, the Northern Railway of France will take the lead in that country by the installation of apparatus in their trains for illumination by electricity. It is probably known, that the lighting of their third class carriages by oil is as poor as the accommodation; in the second class it is better, but sufficient to discourage reading; while in the first class it has been—since the last few years—very good, due to the employment of round burners. The luminous intensity is now raised by the incandescent lights to 6, 8 and 10 C. P. lamps of 30 volts, according to the class of compartment for which they are destined, the current being 2.9 to 3 watts per candle. The lamps are good for 300 hours. Each carriage carries its own apparatus of 16 accumulators of the type introduced by the "Société du Travail Électrique des Métaux," enclosed in groups of two in small boxes, which themselves are placed in groups of four, in two cases fixed one to each side of the longitudinal frames of the car, and readily accessible from the footboards for renewals. Commutators are placed

STATEMENT.

Countries.	Miles open.	Number of passengers.	Goods. Tonnage.	Train-Miles.			Gross Earnings.			Working expenses.	Net earnings.	Gross earnings per train-mile.	Working expenses per train-mile.	Percentage of working expenses to earnings.
				Passenger.	Goods.	Total.	Coaching.	Goods and live stock.	Total.					
												Pence.	Pence.	
United Kingdom....	20 191	845 463 668*	310 308 676	171 758 552	148 500 101	323 598 125‡	£35 130 906	£43 230 717	£81 860 607 (1)	£45 144 778	£36 715 829	58,00(2)	33.48	55
United States.....	166 410	492 000 000	577 000 000	283 797 000	434 700 000	718 497 000	64 549 893	149 738 187	219 557 460 (6)	149 340 000	70 217 460	73.34	49.88	68
Germany.....	26 623	377 000 000	212 000 000	94 392 000	85 077 000	179 469 000	17 320 822	44 634 427	66 618 547 (7)	33 991 783	32 626 764	80.01	45.46	51
New South Wales...	2 359	19 918 916	4 296 713	3 683 813	4 672 283	8 356 096	1 189 231	1 918 065	3 107 296	1 914 252	1 943 044	89 25	51.98	61.60
Victoria.....	2 903	69 546 921	3 654 967	.....	.....	11 807 677	1 644 315	1 450 807	3 695 12[illegible]	2 138 139	956 983	62.91	43.45	69.08
Queensland	2 320	2 370 200*	768 527	.....	.....	3 966 120	348 199	704 337	1 052 536	639 502	413 034	63.69	38.70	60.76
South Australia....	1 660	5 744 487	1 104 122	1 595 957	2 582 329	4 178 286	349 421	863 869	1 213 290	652 941	660 349	69.69	37.50	53.82
Tasmania.....	377	725 724	161 141	.....	.....	908 694	109 888	59 162	169 050	147 944	21 106	44.64	39.07	87.51
New Zealand.....	1 869	3 553 764	2 122 987	2 696 314 (3)	314 175	3 010 489	406 412	709 020	1 115 432	706 517	408 915	88.75	56.32	63 34
India.....	17 564	122 855 337	26 158 953	.....	.....	60 800 165	4 846 101	9 755 073	15 025 174 (4)	7 064 904	7 960 270	59.31	27.89	47.02
Ceylon.....	192	3 076 828*	281 499	.....	.....	690 070	86 528	187 176	276 827 (5)	121 966	154 861	96.30	42.45	44.45
Belgium.....	2 012	67 432 178	2 631 502	14 239 246	10 507 319	24 746 565	2 060 264	3 641 183	5 701 447	3 378 561	2 322 886	55.29	32.77	59.14

Remarks.—* Exclusive of season ticket journeys. ‡ Includes 3 339 428 miles run by mixed trains. (1) Includes £3 498 974 not shown in coaching and goods traffic. (2) Exclusive of miscellaneous earnings. (3) Passenger and mixed. (4) Includes £424 000 miscellaneous. (5) Includes £3 123 miscellaneous. (6) Includes £5 269 380 for miscellaneous service. (7) Includes £4 663 298 for miscellaneous service.

Note.—The information for the United Kingdom, India, Ceylon, United States, Germany, Belgium, is for the year ending December 31st, 1891; that for New South Wales, Victoria, Queensland and South Australia for the year ending June 30th, 1892, and for New Zealand to March 31st, 1892.

COLONY OF QUEENSLAND
SOUTH AUSTRALIA
COLONY OF VICTORIA
SOUTH PACIFIC OCEAN
MAP
OF
NEW SOUTH WALES RAILWAYS
showing
COACH AND OTHER ROUTES FROM THE VARIOUS STATIONS
Scale
Explanation
1893
MACINTYRE RIVER
DUMARESQ RIVER
GWYDIR RIVER
NAMOI RIVER
BARWON RIVER
DARLING RIVER
BOGAN RIVER
MACQUARIE RIVER
LACHLAN RIVER
MURRUMBIDGEE RIVER
MURRAY OR HUME RIVER
INDI RIVER
BOURKE
WALGETT
NARRABRI
COONAMBLE
COBAR
NYNGAN
DUBBO
MUDGEE
FORBES
ORANGE
BLAYNEY
YOUNG
GUNDAGAI
WAGGA WAGGA
QUEANBEYAN
COOMA
MORUYA
BOMBALA
DENILIQUIN
WILCANNIA
MENINDEE
SILVERTON
NEWCASTLE
SYDNEY
ARMIDALE
GRAFTON
TENTERFIELD
MUSWELLBROOK
SINGLETON
MANNING RIVER
MACLEAY RIVER
HUNTER R.
CLARENCE R.
BOGAN RIVER
WARREGO RIVER
PARGO RIVER
LAGHLAN
MURRAY OR HUME RIVER

outside the car for connecting and disconnecting the currents. The effective capacity of each battery is 113 ampère-hours; and they weigh 530 lbs., or, if their cases are included, 860 lbs. The lamps are fitted with brilliantly white-enameled reflectors, fitting into the ordinary oil lamp globes. The covers are so arranged as to permit oil lamps to be substituted for electric if required. In the trials it was ascertained that the electric lamps were a cheaper means of illumination than the oil. For the first named, with an intensity of 10 candles, the cost including installation, maintenance, etc., was 1 penny, less $\frac{1}{10}$, for 3 lamp-hours. With oil giving 7 C. P. it was the same sum for $2\frac{1}{2}$ lamp-hours. A number of cars are now fully equipped and will be run in the express trains between Paris and Lille, but it is expected that oil will be gradually supplanted by the electric lighting in other trains of the same company. The figures as to cost require confirmation.

Comparative Statement of Railway Workings.—In looking at the statement, it will be seen that as regards mileage the United States takes first place, Germany second, and the United Kingdom third. America ranks first in goods tonnage, train mileage and earnings, the United Kingdom second, and Germany, considering her mileage and density of population, an indifferent third. In the earnings per train-mile, Germany takes the lead with 80.01 pence, the United States follow with 73.34 pence, and the United Kingdom third with 58 pence. But in the working expenses per train-mile she ranks lowest with 33.48 pence, then comes Germany with 45.46 pence, and the United States with 49.88 pence. Germany shows lowest in the percentage of working expenses to gross earnings, but it must be borne in mind that salaries and wages—important factors in railway working, especially when the number of persons employed runs into hundreds of thousands—are far higher in America and England, and that if the same rates were paid in Germany the working expenses would not show to such advantage. As regards the Australian colonies, Victoria takes a decided lead in the number of passengers carried, but this is entirely due to the purely suburban railways, whose place is taken by tramways in Sydney. New South Wales takes first place in goods tonnage, and in gross and net earnings; but in working expenses per train-mile, and the percentage of working expenses to gross earnings, South Australia shows to the best advantage. It must, however, not be for-

gotten that in New South Wales and Queensland, the whole of the inland traffic has to be worked over high mountain ranges which considerably increases the cost of working. India and Ceylon show the lowest percentage of working expenses to earnings, but this is easily explained by the extremely low rates of wages paid in these countries.

In the following table a comparative statement of railway workings in New South Wales for the years 1857–92 is given:

	1857.	1892.
Population of the colony	283 000	1 182 500
Miles of railway open	40	2 359
Persons to each mile of line	7 075	501
Passengers carried	329 019	19 918 916
Journeys per head of population	1.16	16.85
Tonnage of goods	20 847	4 296 713
Tons carried per head of population	.074	3.634

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

615.

(Vol. XXIX.—August, 1893.)

RAILROADS IN THE REPUBLIC OF MEXICO IN 1893.

By E. PRIETO BASAVE, M. Association of Engineers and Architects of Mexico.

Translated from the Spanish by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

It is proposed simply to present for consideration various local peculiarities of this country in their relation to the construction and exploitation of railroads; to describe briefly, so far as possible, the difficulties with which they had to contend, and to explain how far those difficulties have been overcome; and, finally, to study the remarkable development which in such a short time has brought within reach of all this means of communication, which was entirely unknown in Mexico 30 years ago.

It is intended also to explain, as fully as the limits of this paper will permit, the results which have been obtained from the introduction of

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

railroads into Mexico, forming an exposition of the progressive increase of traffic in the regions that are now traversed by them, due to the abundant resources which Nature has lavished upon the country, inviting the construction of more railroads in connection with the present terminals, and in other exploitation. It is believed that when what has been undertaken is finished we shall be able to develop the entire country and reward those who come to Mexico, not blindly, like the early builders of railroads, but seeking to invest their capital upon a firm and secure basis, whether contemplating the construction of new roads or the valuable agricultural, mercantile and industrial enterprises which result from them.

About the year 1824 attention was first turned in this country to the necessity of more comprehensive ways of communication to bring into contact the remote regions, not only for meeting the requirements from town to town, but with a general object.

At that time the Government issued its first decree authorizing a contract for the canalization of the Isthmus of Tehuantepec, by means of which both oceans were to be united in one, and Mexico was to become the highway for the traffic of the world.

But difficulties ensued resulting from political causes. It is truly said that the Government at that time was not even powerful enough to insist on its own ideas, and could not protect either the National funds or foreign capitalists seeking to venture their means in enterprises which would be very productive if carried to completion, but who found it very difficult to establish themselves in a country just beginning to form itself. It became necessary to abandon the proper ideals possible in a consolidated nation and to turn attention to the establishment of carriage roads, to which the people were more accustomed, and which seemed to accord with the colonial condition, notwithstanding their narrow possibilities. In pursuance of this policy a decree was issued at that time authorizing the construction of a wagon road from Coazacoalcos to the Pacific as a substitute for the canal project; also, for various other wagon roads, particularly from the city of Mexico to Vera Cruz. Little was done in this direction then, notwithstanding the appropriations made annually for accomplishing the object, the truth being that these were too small for the importance and the number of roads which were necessary. It also happened, moreover, that these insignificant sums were diverted from their objects

and employed for war purposes and in sustaining the governments which succeeded one another with excessive rapidity. For the same reason during this epoch, the maintenance of the old cart roads in condition even for laborious and slow passage, could scarcely be assured. This went on for a period of nearly 50 years employed in granting and withdrawing concessions for constructing railroads, among which figure at the head of the list the Tehuantepec, the Vera Cruz and Mexico and the Northern Pacific, by means of which the country was able to really reap the benefits of the first important line of this sort, that from Vera Cruz to Mexico, opened early in 1873.

It might well be thought, when we consider the topographical difficulties of these first lines which are greater than occur in any other location presented in our country, the refinement which had ensued in the political organization, and the confidence begotten among foreign merchants as to the value of agricultural and mineral elements which we would be able to produce by the new enterprises, that the construction of the rest of the projected railroads would then have been hastened, and that in a brief time we should have developed an extended system, sufficient to bring into action the natural resources of the Republic which had lain dormant for lack of easy communication and exchange. But it did not turn out so; new obstacles appeared, although in smaller numbers, to paralyze the construction of new lines, and not until 1880 can it be said that the formation of the Mexican railroad system began with real activity; since then the progress has been extraordinarily rapid and thorough, so that at the end of the 12 years ending in 1892, 10 283 km. (6 389 miles) of railroad had been built in these regions, with prospects of extension, and by the companies already in the field, who announce that as the conditions develop they will place their lines in exploitation.

In the map attached to this memoir (Plate I), all the lines may be found and they are here enumerated.

TABLE No. 1.

MEXICAN RAILROADS.

	Length of line. Kilometers.
Mexican Railway Company (Limited):	
Mexico to Vera Cruz and branches to Puebla and Pachuca	616

	Length of line. Kilometers.
Mexican National Railroad Company:	
Mexico to Laredo and branches from Acambaro to Patzcuaro, Matamoros to S. Miguel, and Mexico to Salto	1 700
National Construction Company:	
Zacatecas to Ojo Caliente and Manzanillo to Colima....	143
Mexican Interoceanic Railroad Company:	
Mexico to Vera Cruz, with branches from Mexico to Jojutla, from Puebla to Matamoros, Yzucar and Vireyes to S. Juan de los Llamos.....	816
Merida and Progreso Railroad Company:	
Merida to Progreso.....	36
Merida and Peto Railroad Company:	
Merida to Akil.....	99
Mexican Central Railroad Company:	
Mexico to Paso del Norte and Aguas Calientes to Tampico, with branches from Yrapuato to Guadalajara, from Silao to Guanajuato, and from Tula to Pachuca.	2 991
Sonora Railroad Company:	
Guaymas to Nagales.....	422
Hidalgo and Northeastern Railroad Company:	
Mexico towards Tulaneingo and branches to Pachuca and Yrolo.....	190
Sinaloa and Durango Railroad Company:	
Altata to Culiacan.....	62
St. Andres and Chalchicomula Railroad Company:	
S. Andres to Chalchicomula.....	10
Orizaba and Yngenio Railroad Company.....	8
Merida, Valladolid and Progreso Railroad Company:	
Merida to Cansahcab and from Progreso to Conkal.....	97
Tlalmanalco and Chalco Railroad Company:	
Chalco to Amecamua.....	27
Merida and Campeche Railroad Company:	
Merida to Mancanic, and from Campeche to Pomuch....	118
Santa Ana and Flaxcala Railroad Company.....	8
Tehuacan and La Esperanza Railroad Company.....	50
Vera Cruz, Alvarado, Anton Lizardo and Isthmus of Tehuantepec Railroad Company:	
Vera Cruz to Alvarado.....	

	Length of line. Kilometers.
Mexican International Railroad Company:	
Porfirio Diaz to Durango, with branches from Sabinas to Hondo, Hornosa to St. Pedro, and Pedricena to Velardena	914
Toluca and San Juan de las Huertas Railroad Company:	
Toluca to San Juan	16
Cardenas and Rio Grijalva Railroad Company	8
Merida and Yzamal Railroad Company	67
San Juan Bautista and Carrizal Railroad Company:	
San Juan to Altasta	4
Potrero, Cedral, Vanegas and Rio Verde Railroad Company:	
Vanegas to Matehuala and branch from Potrero	58
Monterey and Mexican Gulf Railroad Company:	
Venadito to Tampico	623
Yxtacalco and Mexicaltzingo Railroad Company	20
Puebla Industrial Railroad Company	16
Tecolutla and Espinal Railroad Company	4
Cordoba and Tuxtepec Railroad Company:	
Cordoba to Motzorongo	41
Mexican Northern Railroad Company:	
Escalon to Sierramojada	125
Salamanca and Santiago Valley Railroad Company:	
Salamanca to Jaral	36
S. Marcos and Nautla Railroad Company:	
S. Marcos to Huitzitzitlapan	66
Michoacan and Pacific Railroad Company:	
Maravatio to Ocampo and branch from Angangueo	53
Mexican Southern Railroad Company:	
Puebla to Oaxaca	367
Tonala and Frontera Railroad Company:	
Tonala to Puerta and extension to Frontera	69
Valley Railroad Company	20
Monte Alto Railroad Company	10
Matamoros and Acapulco Railroad Company:	
Matamoros to Tlancualpican	40
Tehuantepec National Railroad Company	240
Marquis and Zimapan Railroad Company	23
Total (6 389 miles)	10 283

The great rapidity with which in this short period so many lines of railroad have been constructed is due to many causes, which have united to produce such a brilliant result; in the first place, the peace of the country, interrupted beforetimes with such frequency, has been unalterably preserved in these last years, so as to maintain the credit of the Government and induce foreign capitalists to come and establish themselves in our country; secondly, the Government, understanding the absolute necessity of means of communication, offered to these enterprises the greatest possible facility, assisting nearly all of them with liberal grants which have been punctually paid.

In previous times the Mexican government, fearful of endangering the public revenue, and perhaps not convinced of the potency of the railroads as a factor in production, extended such meager advantages to the contractors, that all the projects failed utterly. So it went on, as before stated, during 50 years, and it was only possible to change this condition of affairs by assuring peace in the first place, and after that by making great efforts and sacrifices to assist the companies, which efforts were not long in being repaid by the development of traffic and the bringing into action of rich places by means of the railroads as soon as they began to be operated.

In instituting certain comparisons which will appear presently, it is not desired that this country should appear in competition in any manner with the foremost nation in railroad matters; that would be an absurd pretension and improper in a conscientious and serious study; but by comparison it is believed that in none of the very small nations has such rapid impulse been given to railroad construction as in Mexico, the fact being that, while in the United States during the first 20 years of railroad building (1830 to 1850), 12 000 km. (7 456 miles) were built, in Mexico during an equal period of time (from 1872 to 1892) more than 10 000 km. were constructed. If this model could be followed in the coming 20 years, 100 000 km. could be completed, as was done in the United States from 1850 to 1870; or if not, then less than the one-fourth part of them, which would correspond proportionately to the territorial extension; that is, 25 000 km. would have to be acquired, to complete the system already projected, the elements of which will be given in the following pages of this paper. They are submitted for the information of those persons who care to cast their eyes over them, on the accompanying map, where the lines to be con-

structed and which have been consented to by the Government are shown.

In most cases they have been legalized by the community in the hope of being placed in execution at the end of the universal crisis which has oppressed the markets, both native and foreign; when this is over they will proceed without delay. By the time the great World's Fair in Chicago comes to an end, this troublesome situation should be past. Surely the concourse of the highest in all branches of human knowledge which will there unite and join in a common interest, proclaiming ideas, should, we believe, have for a result the disappearance of the obstacles which for two or three years, over all that portion of the globe, have stood in the way of commercial and industrial progress in the Spanish-American nations.

With the object of giving a fair view of the development and increasing progressive production which have attended the railroads since the line from Mexico to Vera Cruz was opened, the writer has set forth the facts in the most concise and clear form possible, arranging them in a table so as to see in relief the gain that each new line has brought to the country, enabling us to appreciate by the series this important truth: "So great is the power of production of railroads, that whenever competition is established between two separate enterprises in the same region, or in analogous zones, the new line, instead of diminishing the entries of the older, increases them considerably"; confirming in this manner a principle recognized in all civilized countries in which railroads have been properly and wisely established, that these elements are creators of wealth. These results, although very imperfect in Mexico, notwithstanding the great impulse given to railroads in late years, demonstrate the correctness of the aphorism by an English statesman who says: "Allow the country to make the railroad, and the railroad will make the country"; but only when our railroad system is perfected will this be fully realized; when we have woven the important, the fundamental, threads which are wanting and which must be built, in order to maintain regular pecuniary relations with the markets of the United States and Europe, then there will be a great gestation of wealth, and the activity already begun shall be in full growth, and Mexico will be able to utilize to its own profit, and the profit of the entire world, its advantageous geographical position and unusual stores of unbounded wealth.

TABLE No. 2.

Mexican Railroads.—Statistics of Operation.

Years.	Mexico and Vera Cruz Railroad.			Mexican Interoceanic Railroad.			Mexican Central Railway.			Mexican National Railroad.		
	Passengers.	Tons, freight.	Gross earnings.	Passengers.	Tons, freight.	Gross earnings.	Passengers.	Tons, freight.	Gross earnings.	Passengers	Tons, freight.	Gross earnings.
1873..	476 287	150 473	$1 830 910*	.....	.....	.....	.....	.....	.....	247 547	.....	$17 425
1874..	459 601	121 935	2 354 845	.....	.....	.....	.....	.....	.....	584 075	298	40 744
1875..	267 776	136 632	2 446 555	.....	.....	.....	.....	.....	.....	486 788	221	43 248
1876..	245 675	132 216	2 221 736	.....	.....	.....	.....	.....	.....	486 000	698	44 146
1877 .	300 591	158 537	2 788 986	.....	.....	.....	.....	.....	.....	565 572	346	53 035
1878..	279 893	169 287	2 958 832	.....	.....	.....	.....	.....	.....	529 333	3 209	75 039
1879..	293 179	190 908	3 340 724	.....	.....	.....	.....	.....	.....	535 806	8 102	89 606
1880..	323 088	219 930	3 791 284	228 053	11 431	$101 793	.....	.....	.....	466 897	18 191	133 489
1881..	331 749	278 942	5 020 784	367 116	49 942	264 618	303 543	7 012	$95 683	903 049	26 234	171 772
1882..	385 621	333 979	6 092 326	411 090	53 382	369 250	491 985	202 304	1 732 713	900 855	105 549	454 853
1883..	409 098	373 389	5 826 276	406 016	56 822	579 956	653 669	167 356	3 603 736	1 071 835	140 185	707 935
1884..	389 421	236 030	3 847 374	634 306	131 385	655 122	761 687	190 423	3 774 591	878 878	254 804	1 260 740
1885..	377 512	246 169	3 416 650	606 510	167 970	676 578	694 894	331 700	3 595 388	839 573	177 679	1 296 114
1886..	367 260	266 432	3 318 361	569 421	148 001	706 818	769 655	255 027	3 940 275	891 711	232 661	1 556 378
1887..	380 153	301 185	3 797 215	621 295	174 194	809 845	797 693	356 448	4 973 102	884 541	307 435	1 658 470
1888..	393 679	351 070	4 046 577	673 169	200 386	912 872	756 560	519 261	5 892 564	907 113	370 300	2 572 599
1889..	444 149	391 627	4 277 685	596 812	190 902	982 411	683 147	576 324	6 517 929	929 685	433 166	3 486 728
1890..	502 139	443 794	4 266 999	657 616	288 836	1 537 106	736 730	694 966	6 699 384	937 527	487 598	3 561 987
1891..	620 988	464 123	4 071 950	795 625	282 311	1 633 248	753 276	1 005 417	7 679 507	998 617	515 164	4 052 842
1892..	No returns given.											

* Mexican currency.

Having considered the exposition of the development unfolded by the railroads, the writer will proceed to study the parts of the system yet to be built, with the purpose, as far as the limits of the paper will permit, of completing the subject.

It will be sufficient to take into consideration only the principal lines in order to demonstrate the annual increase due to the beneficent influence which the new lines have exercised upon those established earlier.

A superficial inspection of the foregoing table is enough to convince one of the rapid advance, not only in proportion to the augmented length of line, but in an increasing ratio which has attended the business and earnings of the four principal enterprises of the country. In fact, the Mexican Railroad Company which, with the exception of its subordinate line from Ometusca to Pachuca, has not increased its kilometrage, has increased its earnings from $1 800 000 to $4 000 000 during the period under consideration, a most excellent showing in view of the very notable circumstance that, during the year 1880, in which the Interoceanic Company began operation, there was a substantial increase in the earnings of the Mexican Company.

With regard to the Mexican Central, it is quite apparent that its competitor, the Mexican National, very far from injuring it by the establishment of its line to Laredo, has stimulated it, both lines showing notable increase in annual entries.

Neither did they suffer in the dreadful crisis produced in the last years by the failure of the crops, the low price of silver, the bad state of the public health in all the more thickly populated places of the country, and the rest of the circumstances which impoverished the citizens and interfered with business; so that, despite the obstacles which, taken separately, tended to diminish the earnings of the railroad, they were able to push forward with great strength everywhere for so long a time, and the growing railroad system has kept up its business and in operation in all the development of the system, extending over the whole region of country, and facilitating communication, both intercontinental and interoceanic.

According to the data received from original sources for the year 1891, the traffic on the Mexican railroads amounted to from 5 000 000 to 6 000 000 of passengers and more than 3 000 000 tons of freight, the gross earnings being $20 000 000 (*pesos*).

At the time of writing it is not possible to assemble the data for the year just past, for there has been no minister in the office of Secretary of Communications and Public Works; but if we take as basis the proportionate increase in the earnings year by year, and consider that in 1892 there have been put into operation the important lines from Torreon to Durango, and from Tecomavaca to Oaxaca, there will be no risk in assuming for that year a total earning of $25 000 000 (*pesos*) for all the railroads.

Nearly $200 000 000 (*pesos*) have been expended in the construction of railroads up to this time, not including the line across the Isthmus of Tehuantepec, which has had so many different estimates and undergone so many changes of plan that it is not easy to give even an approximate idea of its cost. But, however, we repeat, those already opened to operation, wholly or in part, not taking into account the estimates for the rest of the lines hereafter, have cost $200 000 000, approximately. Of this the Government has advanced to the companies nearly $76 000 000, it is said, more than a third part of the whole sum, in form of subventions, which vary from $3 500 to $9 500 per kilometer ($5 600 to $15 300 per mile), according to class and condition of each road.

In three cases only among the more important lines the Government has adopted another system of subvention; these are the Mexican and Vera Cruz R. R., for which, it is understood, a fund of $8 000 000 (*pesos*) was appropriated out of the maritime duties, in a certain percentage of the entries amounting to about $560 000 annually; also the Puebla and Oaxaca, and the Matamoros, Yzucar and Acapulco lines, which drew from the Government 8% interest on the cost of the road when constructed at the rate of $30 000 per kilometer ($48 000 per mile). This value, this almost unheard-of subvention, serves to demonstrate the difference at the present time, when the railroad system meets with general encouragement, and in which the Government has adopted the principle in general of granting no more subventions; only the great necessity of pushing forward the work of the companies which are building lines to the Pacific has obliged it to break the rule and to assist in a powerful manner those who have appealed to it to complete the system.

In a general view of the business from ocean to ocean, and we may say from one end of the Republic to the other, the companies which

are projecting new lines have gone about it with proper energy and after taking into account the business to be secured, to which they will give greater facility, and what capital is required.

The experience acquired upon previous studies and surveys by the Mexican engineers has given them an aptitude for verifying, in the most difficult locations, the economies, in time and money, of construction. The price of labor, always very low in this country, has been cheapened still more since the peons and Mexican laborers have become skilled in the work of which at first they knew nothing ; the facility and economy in the transportation of materials, both native and foreign, which have been carried for ingots, instead of paying dearly for transportation, as was formerly the case ; and, lastly, all the essentials for the exploitation are met and can be utilized anywhere, presenting to the companies, as we have said, a wide field for basing their calculation in a very positive degree, which enables them to do work with great success without assistance from the public.

We may truly say that we have entered upon the second era of railroad building, in that we are able to establish them without subventions with assured success to sustain their cost and meet interest charges on the capital invested. The present improving condition of material productions, which has been proved to exist in most cases, is a guarantee to those who hereafter may come here, to engage in any enterprise, that to secure the expected profit it is only necessary to analyze the business thoroughly, not to waste all the funds in bad management and not to falter on account of questions of expediency for the shareholders.

The third epoch for the construction of railroads is perhaps already late in arriving, but will follow the first two ; and when that time comes such enterprises will be developed as will pay for their establishment in local interests. These will be chiefly small branches to serve as feeders for the main roads, their importance not being great as regards distance covered, but the business they will induce will be very extensive, it being impossible to fix the limit to the local necessities which will arise and which invariably adjust themselves to the measure of the business activities.

It is now in order to make a brief reference to the financial condition of the four principal railroads we have considered, with the object of having it serve as a study for those who may come to renew railroad building in this country. During the year 1891, which is the last one

for which we have the figures, the percentages of net earnings were as follows :

Mexican Railway	42%	of gross	earnings.
Interoceanic Railroad	31%	"	"
Mexican Central Railway	33%	"	"
Mexican National Railroad	30%	"	"

From this it is evident that the Mexican Railway, notwithstanding its excessive construction account, must possess an excellent management, and in turn enjoy excellent opportunities to secure business, the operating expenses being for these two reasons relatively small.

The Mexican Central Railway, which is operated in a well-chosen district, and for the most part with few accidents, unites to these conditions a well-ordered administration and the heavy subventions which it has received, amounting to the sum of $28 000 000.

The Interoceanic Railroad, constructed at a low cost and with good subventions, has been able to sustain its heavy maintenance charges, and to counteract some of the defects of its administration which have consumed a large part of its earnings, and may be said not to have really suffered from these defects, for it is the railroad which earns the largest rate of interest annually.

Lastly, the Mexican National Railroad, which has an enormously high construction account while it did not get such strong subventions, and is not very well managed, consumed on this account* 70% of its gross earnings, which are not very abundant; of the four, in the writer's judgment, it is located in the most disadvantageous position.

The fact is, that while the Mexican Railway has paid between 6 and 7% per annum, the Interoceanic between 8 and 9%, and the Central 13 to 14%, the Mexican National has only realized about 4 per cent.

Doubtless the low earnings of the last-named road will go on increasing from year to year, but at the present time it is paying the tribute due especially to its wasteful construction, for, notwithstanding its being a narrow-gauge road, it has cost 50% more per kilometer than the Central.

In concluding this memoir the writer will occupy himself with the supplementary railroad system as actually projected in connection with the several great lines and for perfecting local communication.

* The author omits to mention here that the Mexican National is narrow-gauge, while the other three are standard gauge; farther on, however, he refers to the first fact.—*Translator.*

Many lines have been granted, the greater part with subventions, awaiting improvement in the financial condition to be built; the developments of these lines, which are given below in Table No. 3, are only approximate, inasmuch that generally they are not yet finally located.

In the accompanying map the probable locations of the lines named are shown.

TABLE No. 3.

MEXICAN SUPPLEMENTARY LINES.

	Length. Kilometers.
Hidalgo and North Eastern Railroad:	
Los Romeros to Tuxpan	250
Alvarado Railroad Company:	
Alvarado to Tehuantepec	250
Mexican Interoceanic:	
Jojutla to Amacusac	30
Sinaloa and Durango Railroad Company:	
Culiacan to Durango	450
Mexican Central Railway Company:	
Guadalajara to S. Blas	350
Mexican National Railroad Company:	
S. Miguel to Monterey or to Laredo 250	
Morelia to Colima 400	
——	650
Merida and Peto Railroad Company:	
Tekan to Peto	60
Merida and Valladolid:	
Cansahcab to Valladolid	125
Merida and Campeche:	
Hecelchakan to Mazatlan	60
Mexican International Railroad Company:	
Durango to Mazatlan	300
San Marco and Nautla Railway Company:	
Huitzitzitlapan to Nautla	140
San Benito and Tapachula Railroad Company:	
San Benito to Tapachula 60	
Tapachula to Tehuantepec Railway 560	
——	620

	Length. Kilometers.	
Mexican Southern Railway Company:		
Oaxaca to Tehuantepec		240
Mexican Pacific Railway Company:		
Mexico to Cuernavaca and Palizada		450
Tonala and Frontera Railroad Company:		
Taltan to Frontera		360
California Bay Railroad Company:		
San Quintin to Rio Colorado	300	
San Quintin to Tiguana	300	
San Quintin to Los Angeles Bay	420	
Rio Colorado to Magdalena	630	
Magdalena to Mexican Central Railway	620	
		2 270
Sonora, Sinaloa and Chihuahua Railroad Company:		
Guaymas, via Alamos to Topolobampo	570	
Topolobampo via Fuerte to Ciudad Guerrero	510	
		1 080
Sierra Mojada and International Railroad Company		450
Zamora and Zihuatanejo Railroad Company		400
Cordoba and Tuxtepec Railroad Company		130
Pachuca and Tampico Railroad Company:		
Angangueo to Yguala		240
National Railroad Company of Tehuantepec:		
Intermediate portion		60
Matamoros, Yzucar and Acapulco Railroad Company:		
Tlancualpicana to Acapulco		340
Matamoros and Matehuala Railroad Company		600
Matamoros and San Luis Potosi Railroad Company		800
Mazatlan and Camargo Railroad Company:		
Topolobampo to Presidio		930
Aguas Calientes, Guadalajara and Chamela Railroad Company		585
Continental Railroad Company:		
Matamoros to Tuxpan	825	
Tuxpan to Tehuantepec Railroad	675	
Tuxpan to Mexico	375	
		1 875

VOL. XXIX, No. 615.
TRANS. AM. SOC. CIV. ENGRS.
BASAVE ON RAILROADS IN MEXICO.
PLATE I.

AMPLIACIÓN DEL DISTRITO FEDERAL Y ESTADOS LIMÍTROFES
ESCALA DE 1 Á 2.000.000

Propiedad Registrada Conforme á la Ley.

Libreria Nacional y Extranjera. E. Sanchez

Escala — 1: 3.000.000

IMP. Y LIT. ESPAÑOLA MEXICO.

	Length. Kilometers.
The remaining lines of this company have not been determined upon.	
Tula, Zacualtipan and Tuxpan Railroad Company.....	345
Ishmus of Tehuantepec Railroad Company to the Guatemala Foundry.....	570
Saltillo and International Railroad Company:	
Saltillo to Jural.....	75
Toluca and Cuernavaca Railroad Company.....	100
Mexico and Zacatula Railroad Company.....	525
Total (9 994 miles).....	16 085

Some of these concessions have lapsed, but as the greater number of them possess subventions and all are lines with a great future, it is believed that in a short time they will be rehabilitated, inasmuch as at the present time there is a sense of solicitude and a very favorable disposition on the part of the Mexican government to push forward the construction of the railroads which are lacking, though not with such great expenditures as was at first necessary, in which there was always blundering and great waste of money by the companies, who nearly all rushed blindly into enterprises regardless of consequences.

We are able to calculate approximately the additional capital required for the extension of the Mexican railroads in accordance with the above enumeration; $300 000 000 or $400 000 000 will be necessary to cover the system of through lines, and, perhaps, as much more to complete the local roads.

This is not an appropriate moment for believing that all this will be accomplished within a very short time, but we may take comfort for the present, while still in the midst of the economic struggle which preoccupies all nations, that we are able to continue building two or three of the more important lines, bringing us near to the establishing of interoceanic communication, which for many complex reasons has been so long retarded, to the injury of the entire country.

The greatest injury by this delay has been to the western territory, in which are situated such rich and important places as Guadalajara, Morelia, Durango, Oaxaca and many others, where also await facile

communication the numerous, abundant and rich products of the tropics—rice, chocolate, coffee, indigo, fruits of various kinds, valuable woods and many other miscellaneous products—which are being lost for lack of consumers, and which, ere long, will be scientifically cultivated and transported to all the centers of consumption, giving rise to a prosperity of which, perhaps, their owners have as yet formed no conception.

The lines on which construction is now being prosecuted are the Tehuantepec National Railway, which it is said will be completed by the end of the present year, thus realizing a desire which Mexico has cherished for nearly a century; the Matamoros, Yzucar and Acapulco Railroad, which extends through the richest and most productive regions of the States of Puebla and Guerrero; and the Cuernavaca and Pacific Railroad, just started at the capital of the Republic, and which will soon reach the State of Morelos and continue its march towards the Pacific, opening up the riches of the unknown and now neglected, but not the less fertile, lands of Guerrero. The Hidalgo and Northeastern road is also under construction to Tuxpan, and other railroads in Yucatan.

Space is lacking to pursue the discussion of so vast a subject. Scarcely more has been done than to call attention to the leading points of our railroad situation, and perhaps these cursory notes will bring out very little that is useful. In endeavoring to study all the circumstances which more or less directly affect the works already built or those we desire to build, they may, perhaps, have been passed over too superficially, and yet it may be said that it has not been easy to consider them all with the desired care; but the subject is too complex to formulate a good and complete study upon the matter as thoroughly as is necessary, to give a methodical estimate of them all without exceeding the time now available, and yet, without the essential gifts for close study and methodical research, perhaps there may be conveyed, between these lines, something more than the small measure of their apparent value.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

616.

(Vol. XXIX.—August, 1893.)

STUDY UPON RAILROADS TO CONNECT GUADALAJARA WITH THE PACIFIC OCEAN.

By S. V. PASCAL, M. Association of Engineers and Architects of Mexico.

Translated from the Spanish by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The study of a railroad line can be divided into two parts which are intimately related to one another, the financial and the technical. The first relates to the probable valuation of the earnings which the line can command, taking as the foundation of its considerations the present traffic between its terminals and, generally, of the territory along its base; the lawful rates it can obtain; the amount of capital that can

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

be secured for the enterprise in question; the profits to be derived; the cost for which, in favorable circumstances, it can be built, and the increased traffic to be developed by the industries and by agriculture at points reached by the line, due to the facility and rapidity of communication afforded.

The second, that is, the technical, belongs to the engineer, embraces exploration of the country for a location, the cost of which shall be the least possible. This problem is truly a difficult one, requiring generally and in all important lines much practice and experience, inasmuch that almost always it must be decided at first sight upon principles which afterwards necessitate profound study.

The comparison of the approximate value of the cost of the line with the provision by the estimated traffic determines whether the study can be adhered to; and, finally, in view of the revised data, the estimate decides the construction of the line.

It should here be stated that, not having the final data of the surveys and estimates for the projected railroads between Guadalajara and either San Blas, Chamela or Manzanillo, the writer proposes, in studying these projects, to advert only to the figures of the traffic as furnished by the Chamber of Commerce of this capital. For the technical information regarding the railroad line to San Blas he is indebted to the kindness of the Chief Engineer, Señor D. Porferio Somelli, and for the data of the lines to Chamela and Manzanillo, respectively, by favor of Chief Engineer Don Carlos Ockon Arronis.

The data furnished by the Chamber of Commerce, in an extended and conscientious report to the State Government, assigns for the movement of merchandise on any one of the three lines of which it treats, 200 000 tons per kilometer, and a like number of passengers. To obtain these figures the Chamber took the amount of annual collections that had been made at the toll houses in the towns along the projected routes, such as Zocoalca, Sayula, C. Guzman, Tepic, Etzatlan, Ahualulca, Ameca, etc., and also the records of the annual agricultural production of Talisco, Colima and Tepic. Such records are the most reliable that could possibly be obtained, for they are derived from the actual traffic and from the official count of the production; they have been taken for the basis of the present study.

In the introduction to the part that relates to the end in view, they say as follows:

"In estimating the freight traffic at an annual average of 200 000 tons, for the least annually, on the lines referred to, we based the subscription on the legal records which are found in the municipal exchange of the capital; those that refer to the traffic have been obtained from the Custom House of Mexicalcingo, which represents the principal part of the freight movement between Guadalajara and the southern part of Talisco, Colima and the Pacific Coast, amounting in the last half year of 1892 to $6 129.83; revenue from tolls upon vehicles and beasts of burden with freight of various kinds entering the city through the custom house; and the traffic of the first six months of the year being greater than of the second, we have deduced the subscription of $12 500 as our estimate for the least annual revenue at that place. At Salida we estimate $10 000, for the road tolls are not so heavy, and we only calculate the produce to be worth $1 per load, which corresponds to a considerable movement, and considering also that the freight pays specific duties, and that the cattle and the like which the railroad would be able to transport pay no duties on entrance, or in passing through the capital, we deduce the total annual freight movement, according to the custom house, amounting upon a conservative estimate to 200 000 tons."

"In calculating the traffic for some of the principal towns of Southern Talisco, which would pay tribute to the railroad at Colima and Manzanillo, and in order to obtain another subscription of reliable data, we looked up the freight movement at C. Guzman, the principal town or cabacera of the ninth canton of the State of Talisco. The results here, according to reliable information from Señor Sullivan, selected by competent persons to speak for the town, amounted to more than 1 200 000 packages of freight of 6 to 8 arrobas (150 to 200 lbs.), approximately, each, in every year of the five years covered by the information; this quantity is equivalent at least to 100 000 tons per kilometer, without including cattle and other animals that will be carried by the railroad.

"The traffic obtainable in the capital of Ojarita del Carmen and Zapopan, representing the major part of that which exists between Guadalajara and the western portion of the State of Talisco, Territory of Tepic, and the States of the extreme western part of the Republic, etc., equals, approximately, that of Mexicalcingo.

"The freight traffic of the city of Tepic, according to figures of bonded merchandise obtained from the custom house there, given me by the illustrious Secretary, Señor Manuel M. Gonzales, was, in the fiscal year of 1891–92, 173 459 packages. Estimates by this officer place the total movement of merchandise at much more than of that which pays duty, because the latter does not include any articles that do not pay port charges. There are many articles which do not pass through the custom house, such as beans and corn, and, according to

persons well known in Tepic, not less than 50 000 bushels of corn enter annually, and the other cereals in proportion.

"It may possibly be that the share of traffic of each capital of territory is unduly large relatively to the remaining towns of this district, among which are contained others as rich and as full of traffic, as Yxtlan, Santiago and Acaponeta; nevertheless, it may still be affirmed with all confidence that this region is a suitable field for the railroad of which we treat, and in a very considerable degree.

"Turning our attention to the present condition of things, in regard to the occupation of this territory by a railroad immediately, we may say that it is almost entirely isolated from the rest of the country, being connected with it only by a road which is almost entirely impassible through neglect; but by means of easy communication this territory may be placed in condition to command both the eastern and western markets of the Republic, and its transformation will be quick and marvelous, for the reason that it is a privileged region and suitable for developing in a high degree a multitude of agricultural and manufacturing industries."

The same may be said respecting the present and future of the cantons of the States of Talisco and Colima, no matter by which route the iron road reaches the Pacific seaboard, for it will bring each of these extensive regions into activity without prejudice to the other; on the contrary, the whole territory will be enabled by means of lateral branches to avail itself of the beneficial effect of the railroads, as was demonstrated in an important technical report rendered recently to the Board of Directors of the Central Railroad.

Besides these factors for appraising the freight traffic existing and to be developed on these lines of railroad, it has been found very convenient to take in connection with them the official records of recent date, which give ready to the hand the agricultural and industrial statistics, etc., in the States of Talisco and Colima and Territory of Tepic. The results are for the most part in favor of there being a railroad from Guadalajara to the Pacific ports, and in effect reproducing what we find given in the "Statistics of the Mexican Republic," by Señor E. Busto, published as an appendix to the Report of Revenue; from them the following figures, giving the principal productions of Talisco, are taken:

Corn	608 410 000 kg.
Beans	20 628 360 "
Wheat	74 310 000 "

Mescal, refined	98 000 barrels.	
Mescal, ordinary	12 397 "	
Rum, from cane	12 320 "	
Palm hats	185 672 pieces.	
Pulque, ordinary	116 250 arrobas.	
Linseed oil	3 650 "	
Vetch	590 520 kg.	
Cotton	2,448 000 "	(Talisco and Tepic.)
Sesame	123 570 "	
Anise seed	93 610 "	
Indigo	9 452 "	
Rice	1 074 360 "	(Talisco and Tepic.)
Barley	2 272 000 "	" "
Cumin	30 054 "	" "
Pepper	5 970 000 "	" "
Chicory	330 860 "	(Talisco.)
Haba beans	862 956 "	
Potatoes	774 860 "	
Masas	19 690 "	
Straw	33 650 000 "	
Beer	16 200 barrels.	
Tobacco	2 422 300 kg.	(Talisco and Tepic.)
Sugar and molasses	2 950 500 "	

Before footing up the total productions of Talisco we must add the product of the manufacturing industries and of mining, cattle-raising, etc., which requires transportation to the State capital, the principal towns of the south, southeast and east of the State of Colima, the Territory of Tepic and to Pacific ports.

Respecting the quantities of the productions, agricultural and other, of the State of Colima, we have taken from the statistics cited the following data of annual productions :

Corn	39 100 000 kg.
Wheat	5 500 000 "
Barley	9 750 000 "
Beans	564 000 "
Cotton	1 500 000 "
Indigo	5 400 "

Rice	1 770 000	kg.
Sugar and molasses	102 000	"
Chocolate	4 250*	"
Coffee	300 000	"
Pepper	395 000	"
Tobacco	10 180	"
Vanilla	148	"
Rum, from cane	327	barrels.
Beer	1 236	"
Mescal, ordinary	3 265	"
Straw hats	6 216	pieces.
Wine of coca	1 632	arrobas.
Tolu	9 854	"

In the following exhibit we give the four principal agricultural productions of the Territory of Tepic, according to the same statistics of the Republic :

Corn	138 000 000	kg.
Wheat	14 000 000	"
Beans	3 250 000	"

In respect of the quantity of rice, sugar, tobacco and cotton which are figured among the productions of Talisco before given, they are assumed to be half of the corresponding quantities in the Territory of Tepic.

In the railroads throughout the country which have as great tonnage as in this case, 50% of the gross earnings are consumed in operating, leaving the other 50% as return on the invested capital.

By the projected line from San Blas to Guadalajara the distance is 348 km. (216 miles), and assuming the average rate to be fixed at 4 cents per ton of 1 000 kg. (2 205 lbs.) per kilo. (7 cents per ton-mile) and 2 cents per passenger (3¼ cents per passenger-mile), there would be earned annually $4 176 000, of which $2 088 000 would return to the capital invested. The capitalization being at the rate of 10% annually, we obtain the sum of $20 880 000 for the allowable expenditure for the construction of the line of which we are treating.

* This amount is in error ; should be between 40 000 and 50 000 kg.—TRANSLATOR.

Similarly on the line to Chamela the distance is 433 km. (269 miles), on which the revenue, calculated in the same manner as before, would allow of a first cost of $25 980 000.

For the Manzanillo line we find analogous results.

The line from San Blas has been examined for the Central Mexican Railway people; from Guadalajara to El Refugio, in a length of 45 km., it has a maximum grade of 1½ per cent. It follows generally the Ameca wagon road, deviating at several points to obtain more uniform gradients. It passes through La Venta, El Reventon, with a small tunnel, Los Lomelines, Huaxtla and El Refugio. At El Refugio it forks, there being two alternates, one by the Sierra de Pajaritos and the other by the Ameca River Valley.

The last would be selected, as it follows the natural water-courses, but for the difficulties which occur, the lowness of the line, and its exposure and very great cost of maintenance.

Beyond El Refugio, until it enters the real cañon of the Ameca River, there are about 51 km. of smooth ground, with light grades and easy construction, save at three or four points of no great importance. The line passes Ameca and follows the right bank of the river. Continuing down the cañon it meets with narrow and difficult defiles, narrow banks which the river frequently overflows, the passage of which in some manner cannot be avoided, and having, in fine, a thousand difficulties before reaching any other town of importance; there we arrive at San José del Conde, having come 104 km. The grade through the cañon does not exceed 1¼% until reaching the confluence of the River Ahuacatlan. At this point, following the river bank, it ascends with a 2½% grade for a distance of about 20 km., which continues until arriving near San José del Conde. On this stretch of 104 km. the average cost will run as high as $40 000 per kilometer ($64 500 per mile), because of the heavy works of construction and for defense which are included.

Returning to the alternate location by way of the Pajaritos, which is the one that in the writer's opinion should be adopted, we will continue the description. From El Refugio to San José del Conde it is divided into three distinct sections; the first extending to San Marcos, passing through the villages and towns of Teuchitlan, Ahualulco, Etzatlan and San Marcos, with a development of 53 km. easy grades reaching to 1½% on very short stretches, without much very heavy

work; average cost per kilometer, $20 000 ($32 300 per mile). The second section extends from San Marcos to Ocote, a distance of nearly 50 km., including the passage of the Sierra de Pajaritos. The line climbs with a ruling grade of 2½%, compensated with grand and bold developments, costly rockwork and tunnels and bridges and viaducts, one after the other. To prosecute this work in the midst of the mountains and with a tunnel of 1 km. long will be very difficult, and the average cost is estimated at $50 000 per kilometer ($80 000 per mile).

The third section, from Ocote to San José del Conde, is 55 km. long. The line follows the ground, and there are not many difficulties; the grades are from 1 to 1½%, following the valley of the River Ahualaltan into which it descends after leaving Ocote, passing through Yxtlan, Ahuacatlan and Tetitlan, leaving the valley by ascending the steps of San José del Conde, where it reunites with the Rio Aveca line just described. The average cost per kilometer is $25 000 ($40 000 per mile).

Engineer Don Resendo V. Corona, by order of the State government, made a study to avoid if possible the principal difficulties which the former lines present. The examination by Señor Corona only indicated a proposed line without estimates of cost. This line left Etzatlan following through the ranchos of Palo Verde, Tlacuache, La Canteria, Puebla de Aconahua, Hacienda of San Rafael, Los Hornitos, La Palma and Los Alamos; then it continues as far as Amatlan de Canas, following a well-known footpath to Palma, then skirting south to the inn at La Silleta, and descending to Amatlan by way of La Canada. This trajectory was 60 km. long with acceptable grades, good opportunities for borrow, an easy development and economical construction.

Besides the principal work which already has been given, this line would require a bridge over the Arroyo of Terbabuena and a tunnel 500 m. long beyond the rancho of Los Alamos.

From Amatlan the line continues to follow the course of the river of that name as far as the point known as Las Juntas; from here it ascends to the pueblo of Garabatoz, passing an extensive "llamora," and below by way of San Valentin to the Hacienda of Tepuchuacan on the north side.

Hence it follows along the right bank of the River Ameca and

passing the confluence with the Ahuacatlan, to San José del Conde, where Señor Corona's examination terminated.

From San José del Conde to Tepic the road is smooth, with light grades passing through Compostelo and the cañon of Miravalles, from which it enters with ease the village of Tepic, the length of this portion being 64 km. and the maximum grade does not exceed 1½%, broken by long stretches of light grade. There is one stretch of 12 km. in the Miravalles cañon, where several bridges and much rockwork are necessary.

The average cost per kilometer is $22 000 ($35 400 per mile).

From Tepic to San Blas there is only one location and a very excellent one, notwithstanding that it is extremely undulating, with a great difference in level from one point to another; the distance is 81 km. and the ruling grade is 2½% passing through Lamedo, La Tortuna, Barranca, Blanco, and following on down to the coast about 30 km. before reaching San Blas. This line has heavy cuts and fills, some hard rockwork and very frequent bridges. The average cost per kilometer on this stretch is nearly $25 000 ($40 250 per mile).

In order to examine the total cost of this line, the foregoing figures are arranged in tabular form, in which are shown the lengths, gradients, cost per kilometer and total cost.

TABLE No. 1.

Estimate of Cost for a Projected Railroad from Guadalajara to San Blas, via the Sierra de Pajaritos.

Division.	Length. Kilometer.	Cost. Kilometer.	Cost. Total.	Grade. Percent.
Guadalajara to Refugio	45	$22 000	$990 000	½
Refugio to San Marco	53	20 000	1 060 000	1½
San Marco to Ocote	50	50 000	2 500 000	2½
Ocote to San José del Conde	55	25 000	1 375 000	1½
San José del Conde to Tepic	64	22 000	1 408 000	1½
Tepic to San Blas	81	25 000	2 025 000	2½
Total	348	$26 900	$9 358 000	
Miles, average cost	216	43 300		

The estimated total cost of the completed line amounts, then, to $9 358 000, as above, in a length of 348 km. (216 miles), which we may increase to $12 000 000 for right of way, station buildings, superintendence, plans, etc.

In this it is assumed that we might expend as much as $20 000 000 on this line, which will earn 10% of that amount annually, a result which would enable the undertaking to be negotiated with the assurance of great success, especially as it may claim an ample subvention, which the Government holds out to the company for its construction.

Unfortunately, the grantee company owns the railway from Mexico to Paso del Norte, with the branch from Trapuato to Guadalajara, and probably it fears that the establishment of the line we treat of would cause competition by opening up a new route for foreign traffic.

This fear the writer believes to be unfounded, because the domestic business is evidently sufficient to sustain the new railroad and earn a profitable revenue; while as to the foreign traffic, notwithstanding that it would take the shorter line, the increased volume of business would make up for the shorter haul. This obstacle, more apparent than real, which the Central Company creates for this line, does not apply to the Chamela line, because it is clear that no line can be established in competition that can obtain larger revenues.

No detailed description of this line is given, for the reason that the complete studies have only been made in part. The résumé which follows will, however, be sufficient.

TABLE No. 2.

ESTIMATE FOR THE PROJECTED RAILROAD FROM GUADALAJARA TO THE PORT OF CHAMELA.

SECTION.	Length. Kilometers.	Cost. Kilometers.	Cost. Total.	Grade. Percent.
GUADALAJARA.				
Cerro de Gachupines	7	$12 000	$84 000	0.75
Avenal	15	12 000	180 000	.50
Santa Cruz	6	25 000	150 000	2.00
Presa del Hurtado	20	12 000	240 000	.50
Tizapan	6	30 000	180 000	2.50
Cacalute	4	12 000	48 000	.25
Canada	6	20 000	120 000	1.50
San Martin de la Cal	30	12 000	360 000	.50
Sta. Maria de las Huertas	10	30 000	300 000	2.00
Arroyo Hondo	6	30 000	180 000	2.00
Quila	25	30 000	750 000	3.00
Toya	30	30 000	900 000	3.00
Tenamaztlan	20	20 000	400 000	.50
Portezuela	8	15 000	120 000	.50
Union de Tula	30	15 000	450 000	.50
Ayugula	10	30 000	300 000	2.00
Autlan	20	15 000	300 000	.50
Obispo	20	30 000	600 000	3.00
Purificacion	70	30 000	2 100 000	3.00
Chamela	90	30 000	2 700 000	2.00
Total	433	$24 200	$10 462 000	
Miles, average cost	269	38 900		

By this résumé it is seen that the 433 km. (269 miles) of this line will cost approximately $10 462 000; and if we add for right of way, stations, etc., as we did in the case of the San Blas line, we obtain a total cost of $13 000 000, on which capital 16% can be earned at the present moment, and probably in time this can be doubled.

In consequence, a company has been organized to undertake this work after verifying the estimates previously prepared, which the writer believes are very nearly correct, having been obtained from local sources and in part based upon the study.

Respecting the line from Guadalajara to Manzanillo, it will probably follow the same line as before as far as Tizapan, from which point it will continue on through the following towns:

	Distances. Kilometers.	Grades.
Hacoalca	36	level
Sayula	56	"
La Cuesta	12	2%
Hapotlan	20	1%
Hapoiltic	20	½%
Tuzpan	30	1%
Tonila	40	2%
Colima	40	1%

The writer does not know the studies which have been made respectively for the company; but he does not believe they will vary much in distances and grades from those above indicated.

From Colima to Manzanillo a railroad has already been constructed and is in operation to Cayutlan, Armeria, Guaracho and Coquimatlan. Its length is 95 km., and consequently the total length of this line will very probably be 403 km. (250 miles).

Respecting its cost, it apparently will not differ greatly from the lines previously studied, inasmuch as the topographical difficulties are distributed about equally. Consequently, we may estimate for standard gauge a cost of $30 000 per kilometer ($48 300 per mile), and of $20 000 for the narrow gauge, which is what has been adopted. With this data the resulting cost of this line will be nearly $8 000 000, and so will need a traffic of 200 000 tons and an equal number of passengers, from which the company which has undertaken the enterprise expects brilliant results.

The writer has gone to the bottom of all the previous considera tions for determining the traffic from the present business between the points from end to end, but it is probable that what was obtained in the early days of the exploration will be doubled by the development of the great natural resources which are contained in the regions to be traversed by the lines which have been considered.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

617.

(Vol. XXIX.—August, 1893.)

DISTINCTIVE FEATURES AND ADVANTAGES OF AMERICAN LOCOMOTIVE PRACTICE.

By DAVID L. BARNES, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The locomotives of the United States are not so different from those of foreign countries as might be supposed from the outward appearance; most of the differences are in details, and result from differences in operation, which demand in the United States a large increase in the general dimensions. In studying distinctive features of locomotives of all countries, it is necessary to know in minute detail the conditions of operation under which each class of locomotives is worked, as it is generally found that engines everywhere are well adapted for the work they do. The main difference between locomotives used here and in other countries is a necessary result of the difference in environment. In other countries, generally speaking, the distances are short, competition small, wages low, and money

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893

rentals moderate; in some a governmental control removes all competition. In the United States, long train runs, high wages, sharp competition and high rates of interest define the method of railroad operation so clearly that it is practically beyond the power of any individual company to vary much from the almost universal practice of running heavy trains. It is this necessary policy of heavy train loads that gives rise to the wide difference which is found in maximum hauling power of the American and foreign locomotive. This increased power demands more weight for adhesion and greater steaming capacity; therefore, one finds the American engines heavier and the boilers larger for similar classes of work. This is shown by Tables A1, A2, A3, which give the comparative dimensions of locomotives of various countries.

Many of us in the United States have thought that certain details that are universal here, such as the equalization of the weight between driving wheels, the four-wheeled swiveling and lateral motion truck, outside cylinders, the fire-brick arch and iron tubes, etc., are not commonly used in other countries, and formerly they were not; but now equalizers are common in England, they are standard in Germany, common in France and in other European countries. Outside cylinders are quite universally used in Germany, are common in England, and frequently used in France, Italy and other countries. Fire-brick arches, iron and steel tubes, and lateral motion swiveling trucks are quite common, although not the rule everywhere; so that in looking for such general features of design of locomotive details as are peculiar to the United States, one finds at the present time but little beside steel fireboxes, bar-frames, cast-iron wheel centers and tenders with swiveling trucks. There are many peculiarities in minor details, but these do not affect in any material way the economical operation of the engines.

The use of cabs is dependent, not upon the country, but upon the climate, and they are generally found where the winters are severe. As a rule, all differences in the designs of details can be traced directly to the relative prices of labor. Where labor is high, designs are simple; duplication and interchangeability overrule minor features of durability and efficiency, and in general cast pieces are used instead of wrought. For instance, in the United States the duplication of parts receives more attention than in foreign countries, and it is common to

use a clumsy, heavy, cast-iron piston, that requires less hand labor than the foreign type of piston (the Swedish), which is one of forged steel, very light and strong. Also driving-wheel centers are here made of hard cast iron, while in Europe they are almost universally made of wrought iron.

We are all more interested in such features of locomotive construction as affect the operation than we are in the parts which affect the cost of repairs, for the reason that the other costs of locomotive service are the major part of the total and greatly exceed the repairs. Again, the cost of repairs is so dependent upon the facilities and the price of labor that it is impossible to learn much about the relative merits of designs from a study of the cost of repairs in different countries. Facility for making repairs is the all-important factor of repair costs. Take, for instance, the renewal of driving tires. In this country it was formerly the custom to take an engine into the shop for repairs whenever the driving tires needed turning; in this way the repairs of locomotives were largely dependent upon the durability of the tires. Now, this has entirely changed, and in the most advanced shops general repairs are made only when they are needed. A locomotive may come into the shop in the morning with bad tires and axles and be sent out again at noon with a new set of wheels complete or a new set of tires put on ready for use. The improvements in handling heavy parts and in other facilities for making repairs has materially reduced the cost of keeping up locomotives, so that it is impossible to say what are the advantages of those details of construction which are more common in the United States, without knowing the comparative facilities for making repairs; and furthermore, the difference in the condition on different roads in any one country, in the United States for instance, is great enough to give entirely different results in the cost of locomotive repairs per mile run.

Lack of accurate information has led to considerable discussion within the past two years about the mileage of locomotives before being sent for "general repairs"; but there is no accuracy in comparisons in matters of this kind between locomotives used in different countries, as the conditions are so different. It is not to be expected that a locomotive hauling heavy trains can run so long without a general overhauling as with comparatively light trains. However, it is not the weight of train that governs the mileage made before "general

repairs." The term "general repairs" is indefinite, and some roads keep up the majority of the so-called "general repairs" without taking the locomotives into the shop, while on the other roads some of the "running repairs" are classed as "general repairs," owing to the lack of facilities which compels the locomotive to be considerably dismantled before the parts needing repairs can be made accessible. Therefore, in considering the comparative features of locomotive practice of different countries, the writer has adhered closely to the general features of construction, omitting the minor parts, about which it is impossible to reach a conclusion without knowing in minute detail the conditions and facilities in each particular case; also, such special types of engines as are used in suburban service and for heavy grades are omitted, as they are not common enough to entitle them to be classed as regular practice.

It is not within the scope of this paper to say much about different methods of operating locomotives, but operation so controls designs that one must be understood if the reasons for the other are to be comprehended. The dispute about the economy of running heavy trains has arisen almost solely on account of a lack of definite information on the subject. One may safely grant that if there was any defect in the policy of heavy loads, the exceedingly sharp competition in the United States would have long ago developed the defects, and we should now find some of our roads hauling light trains at frequent intervals. To the contrary, the practice of heavy train loads is universal here. An examination of the cost of freight train expenses in this country, as given by Fig. 1, will show how great is the gain by increasing the train loads when the price of fuel is moderate. The average weight of a foreign freight train, exclusive of engine and tender, is approximately 450 tons. Trains are much heavier on the continent of Europe than in Great Britain. The average weight of an American freight train for level roads is not far from 1 350 tons. Table B gives the data on which Fig. 1 is based. In this table the coal used per ton-mile of total train is taken as a constant for all weights of train. This is only approximately correct, but it is quite near enough for the comparison now being made, as the coal per ton-mile of total train does not vary much with different train loads when the power of the locomotives is in proportion to the train.

The coal per ton-mile of total train is taken as .1275 lb. This corresponds with good practice in the United States. The wages of train crews in this country, on any one road, are nearly the same for all trains.

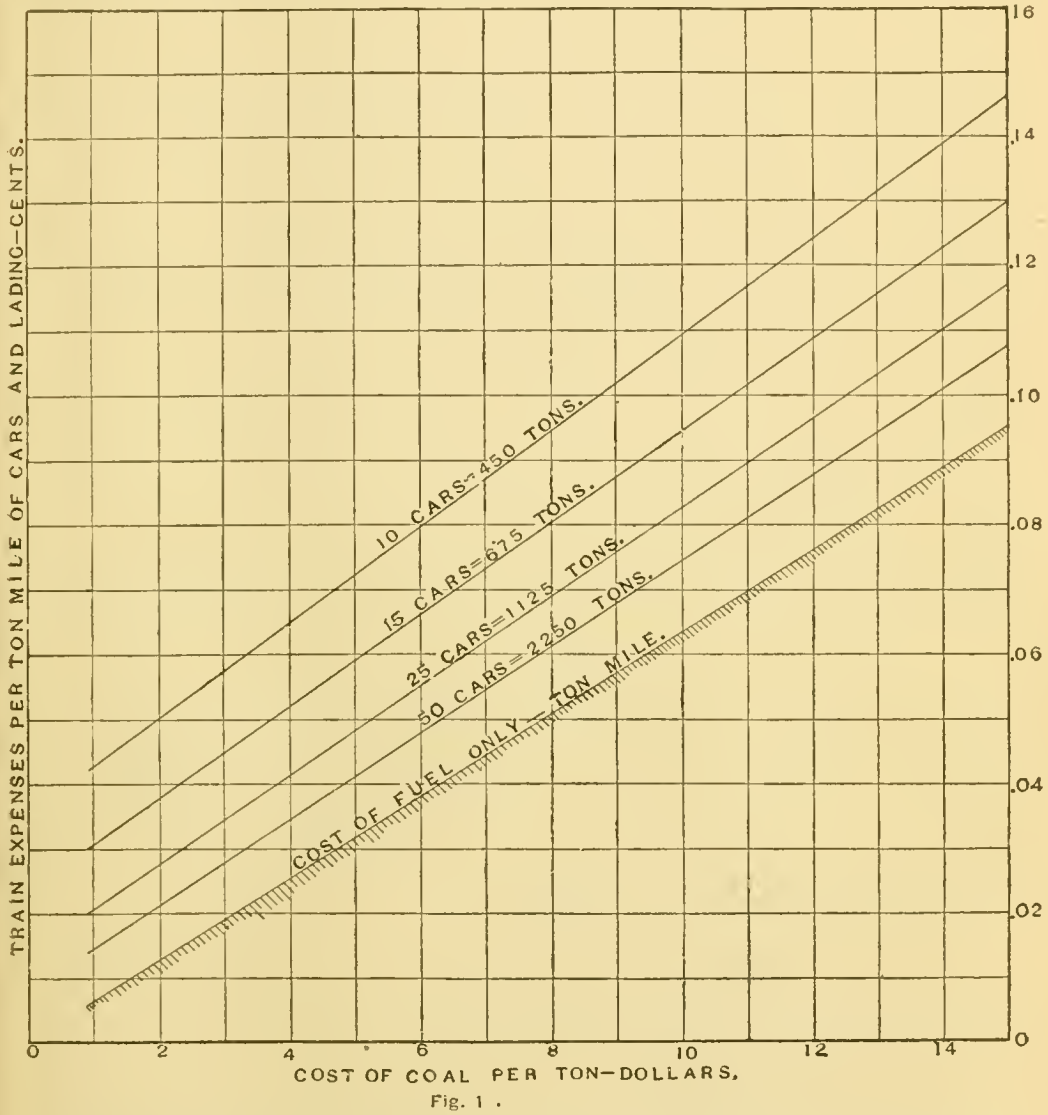


Fig. 1.

Diagram showing the decrease of train expenses per ton-mile of cars and lading accompanying an increase in the weight of trains and with varying prices for coal.

TABLE B.

Number of cars.	Weight of cars. Tons.	Weight of locomotive and tender. Tons.	Engine crew wages per mile run, Cents.	Train crew, wages per mile run. Cents.	Coal used per ton mile of total train. Pounds.	Oil, waste and repairs for locomotives per mile run. Cents.
10	450	70	5.33	7.25	.1275	3.62
15	675	75	5.33	7.25	.1275	3.62
25	1 125	85	5.33	7.25	.1275	3.62
50	2 250	95	5.33	9.25	.1275	3.62

The cost per useful ton-mile for train wages is, in general, the controlling element here, and it decreases as the train loads are increased. In the fuel account there is a saving from heavy train loads up to the point where the engine is excessively overloaded. This is frequently observed from tests of locomotives, but no account is taken of it in the diagram. Take two locomotives and give one a heavy and another a light train; the one with a heavy train will use more coal per mile, but there is a greater useful load in proportion to the dead load of locomotive and tender, and the resultant coal per useful ton-mile is less with the heavy train than with the light train. This reduction in cost of transporting useful loads goes on, even after the load is increased, to a point where the scientific steam engineer would deem the locomotive to be too much overloaded for the economical use of steam. So much bearing does the environment of condition and cost of wages have on the policy of locomotive operation, that in the extreme cases where fuel is less than $1 per ton, the most economical train load is the maximum load that can be hauled by one engine almost regardless of the economy with which the steam is used; this is shown by Fig. 1. So, then, in the United States, heavy trains, high wages, sharp competition and high rates of interest, fix the main distinctive feature of American locomotive practice, which is the greater hauling power of the locomotives. This greater power is obtained in two ways; first, by using locomotives of greater weight, and second, by forcing the boilers to a degree almost unknown elsewhere.

Outside of the greater hauling power, which necessarily requires greater weight and larger parts, and the forcing of the boilers and the machinery, which increases the wear and tear, there is not as much difference in locomotive practice here and in other countries as is generally supposed. From the external appearance of locomotives of different countries, one is led to expect important differences in the vital parts of construction; thus the smoothly encased European locomotive, with a weather shield instead of a cab, often appears to be quite a different machine from the American locomotive with its structural parts exposed to view and with a small house on top of the boiler; yet the organic differences are really small. Each has a pair of single-expansion steam cylinders, either inside or outside of the frames, to which the steam is admitted, and from it allowed to escape by a single plain slide valve actuated by a link motion and eccentrics. The boilers

are both internally fired and have approximately the same arrangement of tubes and parts. The frame construction in both consists of two horizontal and longitudinal beams, made either of bars or plates. The guiding and carrying trucks are perhaps more generally used in the United States, but not to an extent that would justify the claim that a swiveling truck is a distinctive feature of American locomotive practice. Carrying trucks have sometimes two wheels, and again four wheels. Sometimes they swivel, and in addition swing laterally. Where they do not swivel or swing laterally, considerable end play is allowed in the bearings, which gives them, to a considerable extent, the equivalent of a lateral motion. Many engines in the United States are without lateral motion in the trucks, and in Europe one finds many trucks that both swivel and move laterally.

The drivers and connecting rods of locomotives of all countries are alike in all functions; and so on, throughout the principal details, there is but little in the general purposes of construction that can be considered distinctive differences, or differences that should materially affect the economy of operation under the same and equal conditions. However, few as are the important differences in general features, yet there are many and great differences in detail when viewed from the standpoint of the experienced locomotive builder. These differences do not affect the economy of operation, but govern somewhat the durability and affect mainly the amount of labor required in construction, and thereby influence the first cost. The main distinctive features are as follows:

Boilers.—Both in Europe and in the United States, one finds the straight top, the wagon top and the Belpaire boiler. It is impossible to say which of these three types is most used in the United States at the present time ; but it appears from observation of the engines built in all countries during the past two years, that there is a prevailing tendency toward a straight top boiler, with a Belpaire or radial screw stay firebox. The crown bar boiler is falling into disuse, owing to its greater weight for equal power and the trouble which it gives when the feed water contains scale-producing compounds.

The difference between the Belpaire and the radial stay boiler lies in the shape of the top of the firebox ; it is rectangular for the Belpaire and semi-circular for the radial stay type, as shown in Figs. 2 and 3. The crown bar boiler is shown in Fig. 4.

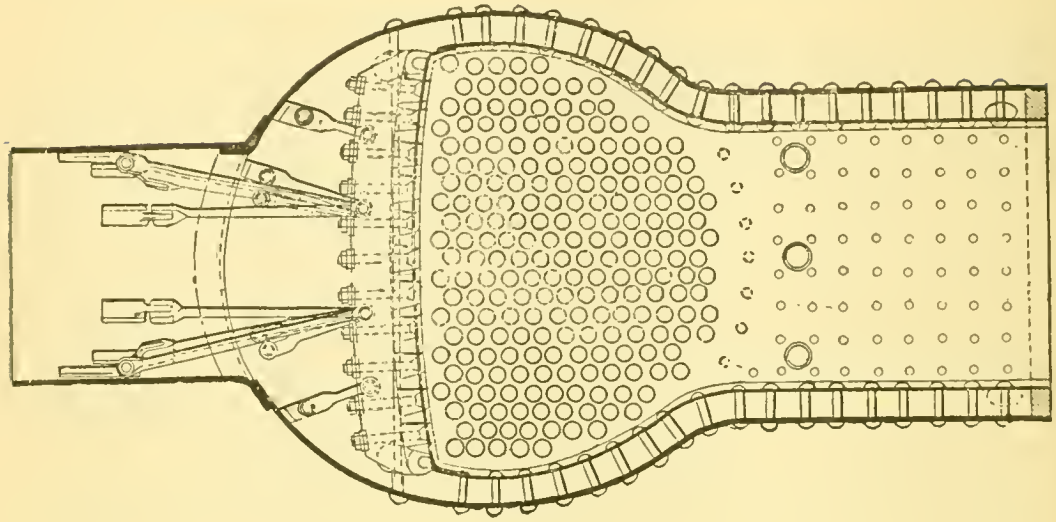


Fig. 4.
American Crown-Bar Firebox.

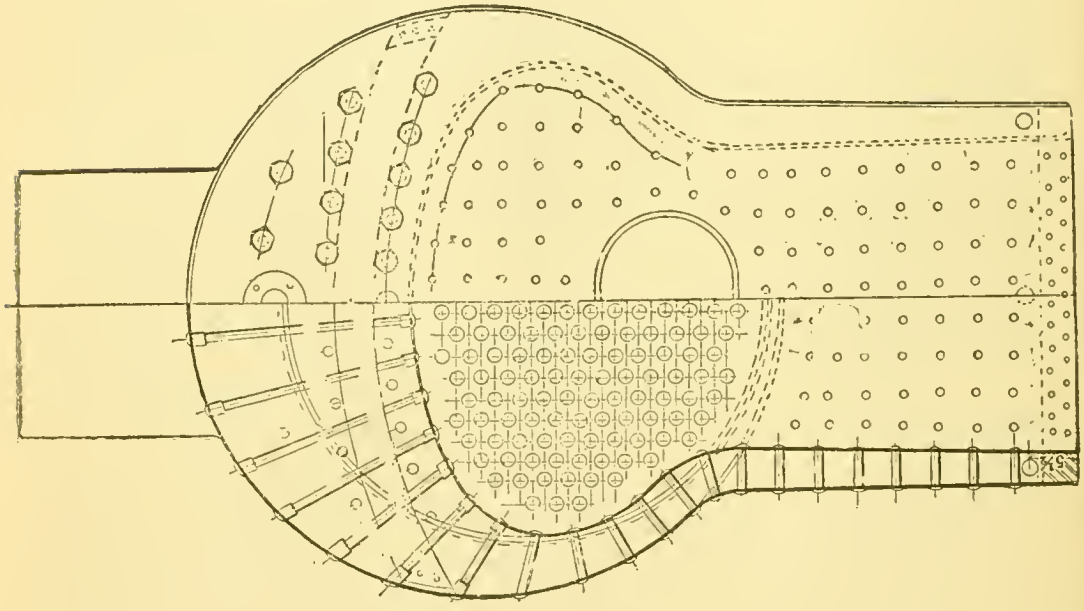


Fig. 3.
American Radial Stay Firebox.

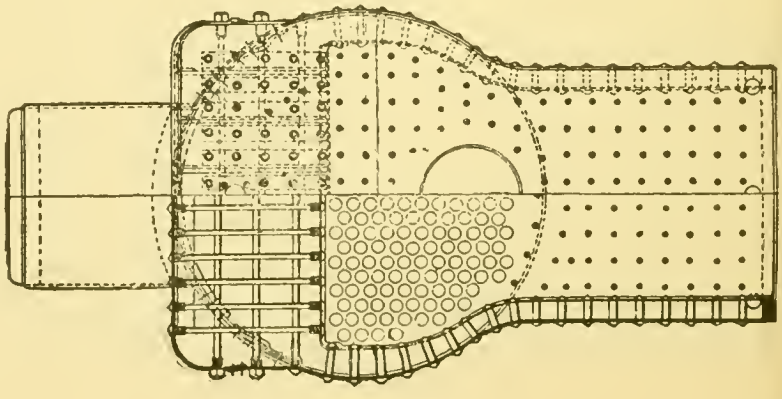


Fig. 2.
American Belpaire Firebox

In some sections of the United States there are large amounts of fine coal and slack that cannot be burned in the ordinary locomotive; and in such places here, as in Belgium, one finds a peculiar construc-

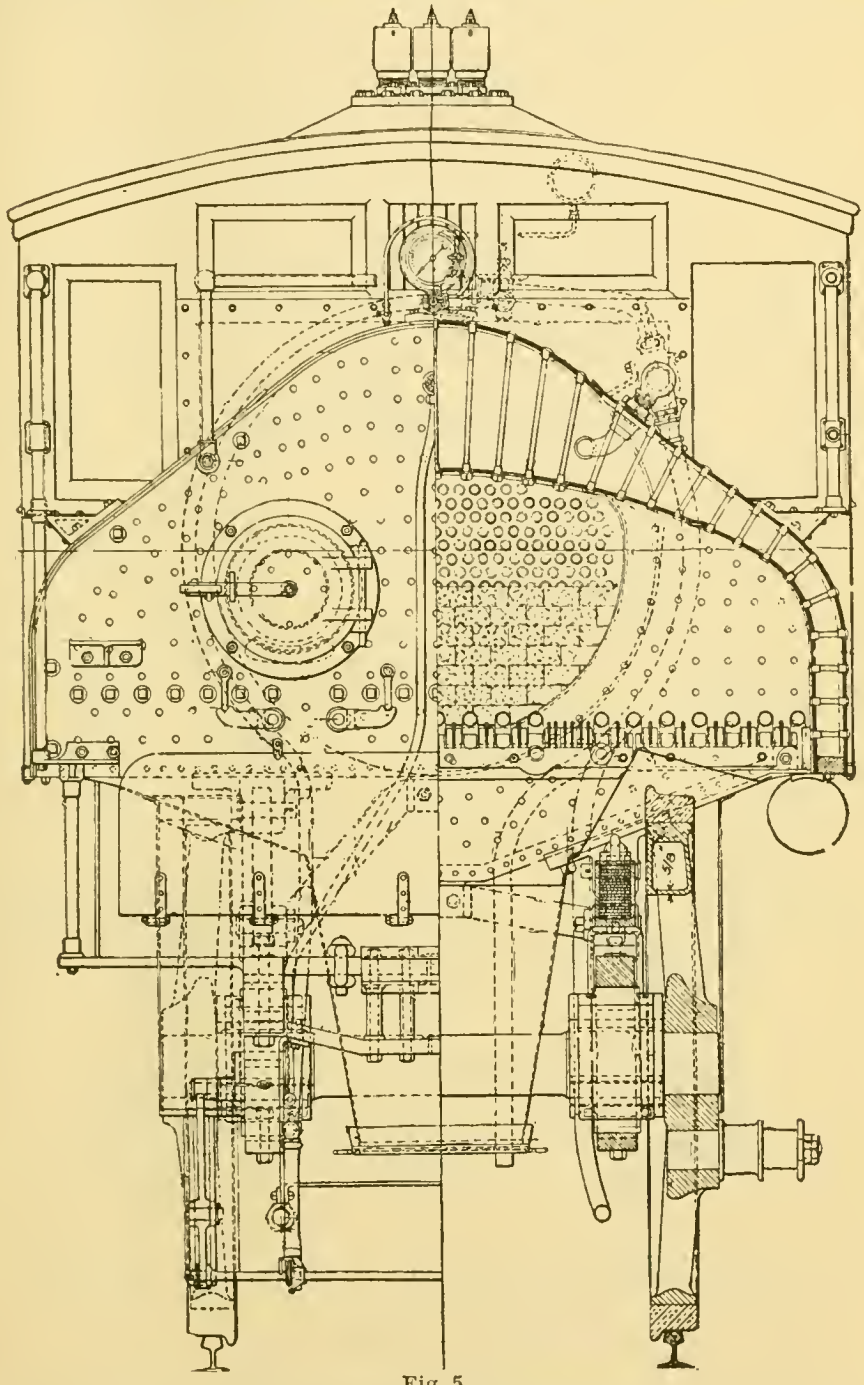


Fig. 5.
American Wootten Radial Stay Firebox.

tion of locomotive fire-boxes. In this country the most common type for fine coal is the Wootten. The form generally used is that shown in Fig. 5. A new form, having a Belpaire top, has been proposed.

It is not unlike that used in Belgium, and shown in Fig. 6. The Wootten type of boiler has been very successful where there is a sufficient quantity of fine coal; but on some western roads in the United States, where it has been tried, there has not been enough fuel to keep

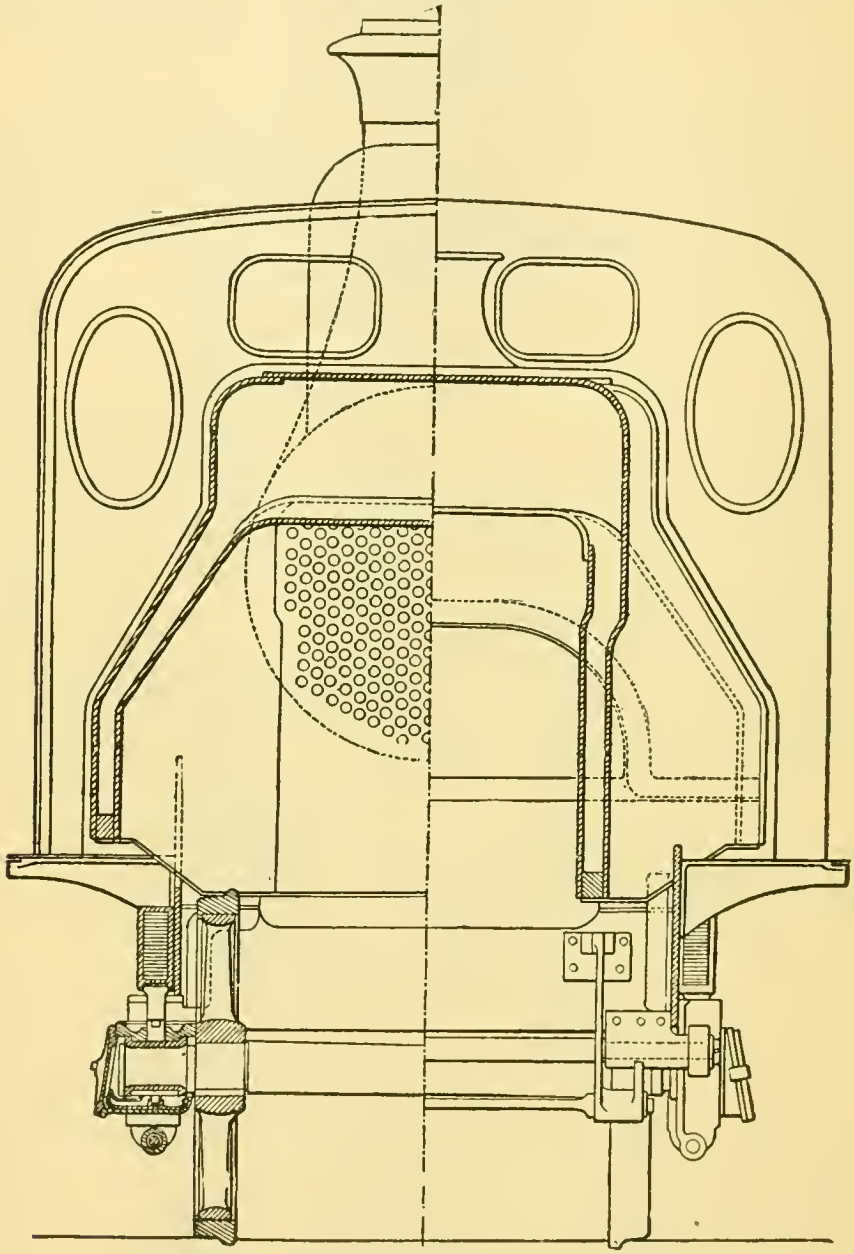


Fig. 6.
Belgium Belpaire Firebox.

the engines supplied. Add this to the disadvantage of having to keep in stock two classes of fuel for engines at the same terminal, and the difficulties experienced with the large crown sheets, and the reasons are found for the infrequency of this type of firebox in sections of

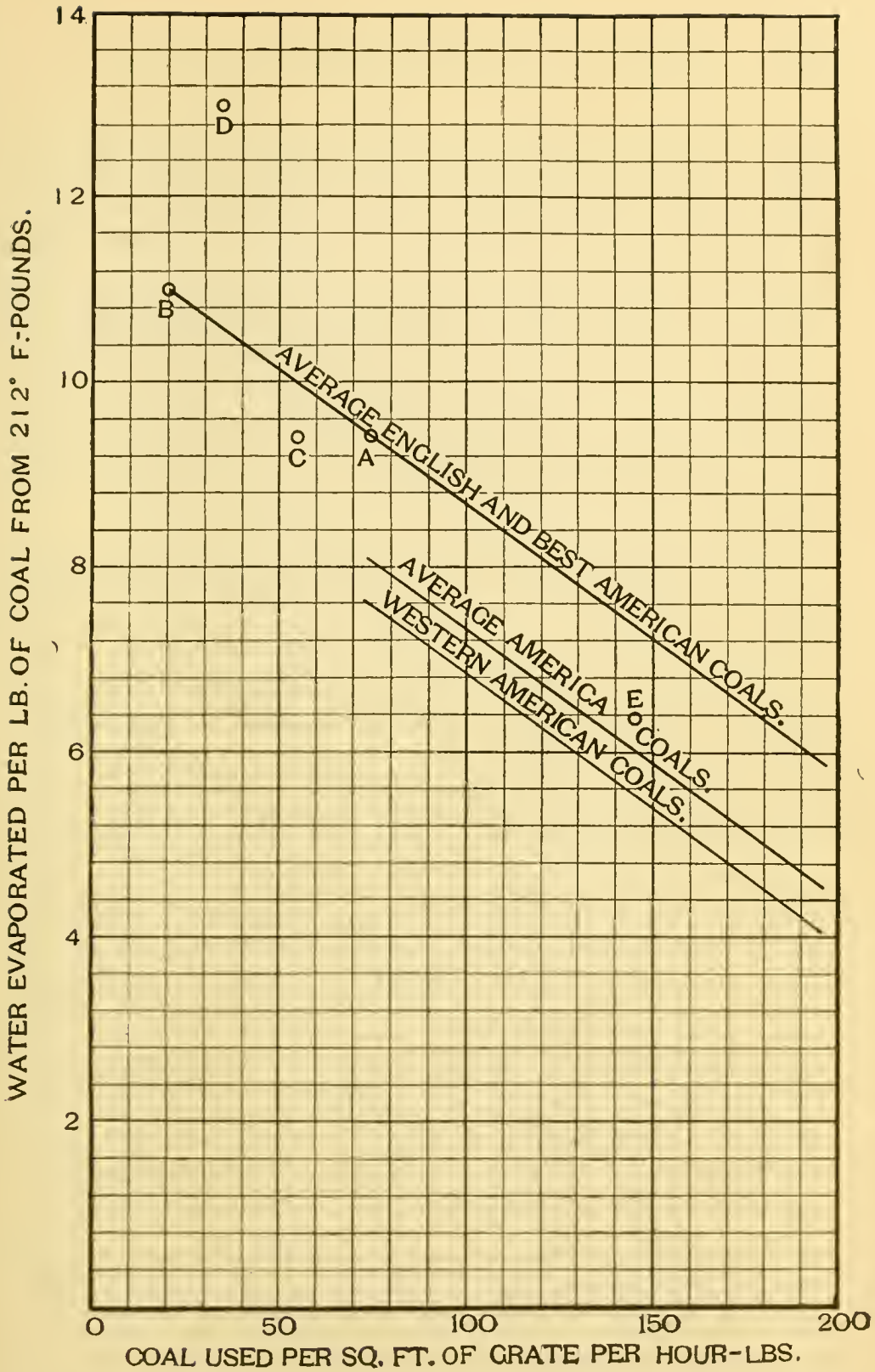


Fig 7.

Diagram showing the decrease in evaporation of water per pound of coal from and at 212° Fahr. which follows an increase in the coal burned per square foot of grate per hour, with English and American coals.

NOTE.—A to B = English practice.
C = English coal as determined by Rankin.
D = English coal as determined by Kennedy and Donkin shop tests of a locomotive.
E = American coal—Brazil block—Indiana—Goss, at Purdue University shop tests.

the United States remote from an abundant coal supply. Locomotive boilers with grate areas as large as these do not use good coal economically, as the limit of economical increase of grate area for free-burning fuel is exceeded. As seen from Fig. 7, an increase in grate area, which is, of course, followed by a decrease in the rate of combustion of coal per square foot of grate per hour, is conducive to economy; but there is a limit to this increase, which cannot be exceeded without loss from incomplete combustion and excess of air supply through the grates. Large grates are difficult to cover properly, and if the fuel is free-burning it is impossible to regulate the fire accurately, and much heat is lost by the blowing of the safety valves when the train is at a station or while descending grades.

There is nothing, therefore, in the general shape and design of boilers in locomotives that can be said to be distinctively American or foreign; but when we look into the materials of construction, we find the American locomotive boiler differs materially from all others, and it may be said that the use of steel for fireboxes is distinctively an American practice. In Great Britain, where all portable engine boilers and marine boilers are built with steel fireboxes, there is not one railroad company using steel for locomotive fireboxes, and there are but a few steel locomotive fireboxes in the whole of Europe.

The tubes of foreign locomotives are more generally made of brass, and in the United States of iron and steel. From an American standpoint, copper fireboxes and brass tubes have no advantages that would induce the railroads here to use them. Good steel fireboxes do not crack, and good iron tubes last so long that the cost of depreciation and repairs depends more upon the purity of the feed water and the care which the boilers get in washing out than upon the material of the fireboxes and tubes; and no one here believes, so far as the writer knows, that brass tubes or copper fireboxes would have a longer life or cost less in the end than good steel boxes and the best iron tubes. It is true, of course, that copper sheets and brass tubes, even at a high price, are cheaper in the long run than bad steel sheets and inferior iron tubes at prices next to nothing; but careful railroad companies do not use bad material for firebox sheets and tubes. The best steel fireboxes last in service from 12 to 15 years. The average life is much less, and is about the same as that of the copper fireboxes used in Europe, which, according to the repair statements of some foreign railroads, is from 8

to 10 years. The cost of repairs resulting from broken stay bolts, burned sheets, and cracks due to scale deposits and vibrations, which are common to all locomotive boilers using bad water, regardless of the material of the fireboxes and tubes, is so great that the replacement of steel firebox sheets that are worn out by normal service is not such a comparatively expensive repair as might be supposed. The scrap value of a steel firebox is small; in fact, may be considered *nil;* but it is purchased for about 4 cents a pound, while copper sheets cost from 20 to 30 cents a pound. The scrap value of copper is uncertain, and depends upon the market. Ten cents a pound is not too high an estimate for the loss per pound of copper between the first cost and the scrap. This difference will permit the steel firebox to be renewed at least twice, and a closer estimate shows that in this country, with the prevailing prices, two steel fireboxes can be put into a locomotive boiler for a cost, including labor, that will not exceed the net cost of a copper firebox with an allowance for scrap. Each renewal of a cracked copper sheet costs much more than the renewal of a steel one, and cracks are to be expected with bad feed water and careless boiler washing, no matter what the material. Even if the copper was more durable than the steel firebox, the fact remains that the American locomotive has practically passed its period of usefulness after about 10 years of service on the prevailing American plan of running heavy trains and pooling engines. This, taken together with the continual development in size and construction of engines in general, tends to so lessen the period of years during which a locomotive is used in this country, as to make it neither advisable nor desirable to put into construction high-priced material, or complicated parts requiring much hand labor, to get a longer life of any part than the life of the engine as a whole. Steel of a proper kind is as good for locomotive boilers as for marine boilers, and those who formerly used copper for marine fireboxes have long since abandoned it for steel, this material having been found to be the more satisfactory.

It has been claimed that an advantage accrues to a railroad company using copper and brass for heating surfaces on account of the greater conductivity of those materials; but this apparent advantage is reduced by the loss due to the greater thickness of the copper sheet; and considering the probability that iron and steel will convey heat from the fire to the water faster than the water can absorb the heat,

there is little, if any, actual advantage in conductivity left for the brass and copper heating surfaces. A very little scale will remove entirely any advantage there might be found otherwise in the greater conductivity of brass and copper. Americans are not without experience with copper and brass in locomotive boilers, and it may be accepted that the continued successful use of steel fireboxes and iron tubes in this country is a distinctive feature of American locomotive construction, and one that actual service has shown to be economical under American conditions of railroad operation; and there is much reason to believe that these materials would be quite as economical in any other country, especially as nowhere else are the fires in locomotive boilers forced as much as they are here. The continued use of copper fireboxes in foreign locomotives, after so much marine experience with steel, is a surprise to American railroad men.

Otherwise than the firebox material and the differences in general dimensions given in Tables A1, A2, A3, there are no important distinctive features of American locomotive boiler construction.

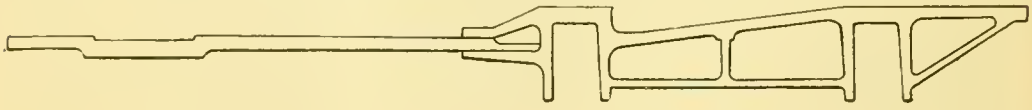


Fig. 8.
American Bar-Frame.

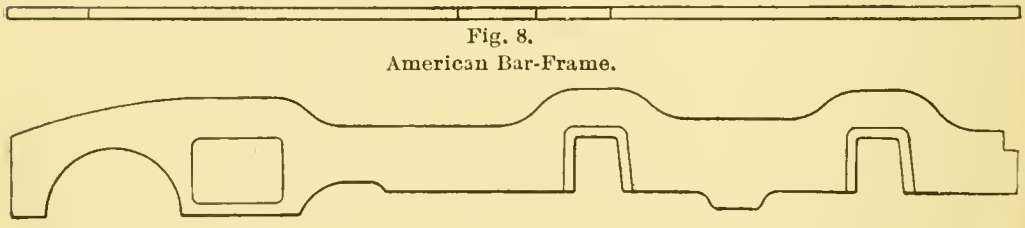


Fig. 9.
Foreign Plate-Frames.

Frames.—The American locomotive frame is universally of the bar type, while that of the foreign is generally of the plate type. These types are shown in Figs. 8 and 9. It may be said that the bar construction is an American plan, as it was first generally adopted here, and it is a popular idea that it was designed to give locomotives ver-

tical flexibility on rough track; but for this it was unnecessary after the adoption of equalizing levers to connect the points of support and to allow the individual carrying-wheels to rise and fall without causing excessive changes in the weight thereon. In fact, the bar-frame has been so securely attached to the rigid and stiff boiler shell that its vertical flexibility, so apparent when the bar-frame lies in the frame shop before erection, disappears almost entirely when it is placed on the engine and secured to the boiler. American builders of locomotives have been criticised for the construction of a bar-frame, on the ground that such a frame is stiffer than a plate-frame laterally, and therefore not so well adapted to the perhaps more crooked roads of this country; but there is no just ground for such a criticism, as the difference in the stiffness of the bar and plate-frame is apparent and not real. As these frames lie on a machine-shop floor, the plate-frame is the more flexible laterally; but if both are placed in position and braced, as they always are, there is no practical difference in the stiffness of them. Both form part of a deep horizontal girder, having heavy chords, the girder as a whole being attached to a stiff and rigid boiler. It is practically true that neither the plate nor the bar-frame has a superior lateral or vertical flexibility which results in any beneficial effect on the action of engines in service. However, some engines have been built in this country without much lateral bracing, and with the boiler barrels so high as to render the attachments to the frame thereto more flexible, and these engines have therefore more flexible frames than is the general practice; but, so far as can be seen, the results from service are not different from other engines having comparatively stiffer frames.

The bar-frame has the advantage of giving better opportunities for attaching the details of the engines, but the plate-frame being without welds can be made with more security from breakage. In this country the bar-frame lends to the engine the accessibility necessary in cold weather, when oil congeals and the motion-work needs constant watching. So, too, it facilitates the examination of the machinery in the short intervals of stopping during long runs. Probably this advantage will continue in the future, as it has in the past, to promote the use of the bar-frame in this country, where the extremes of weather and the rough handling of engines require all parts to be accessible and within the range of the engineer's and fireman's eyes as they look

about the machinery during the short stops on long runs. In some other countries it has been found practicable to oil the main bearings of the engines from pipes leading from the cab (a manifest advantage with the deep plate-frame which obstructs the oiling); but here the extremely cold weather makes such a plan impracticable.

Recently, to avoid breakages of welded bar-frames, some American builders have made them from rolled steel slabs, the slabs being rolled from 3¼ to 4¾ ins. thick, and then planed on both sides and cut out on slotters to the shape and form of the welded frames. The objection to this is the increased cost and the difficulty of welding the steel if it is broken in service. On the other hand, improvements are being made in the welded iron frames by using muck bar instead of scrap-iron for the shapes. Scrap in this country now contains such a large and unknown percentage of steel that it is no longer safe to use it for parts that give much trouble from breakage.

It is not to be understood from what has been said here that slab frames do not break, for they certainly do; but not as frequently as the bar-frames; yet the cast horn-blocks used on slab frames often break, so that altogether there may be after all no advantage with a slab-frame in point of freedom from breakage.

Equalization.—The equalization of weight between wheels, so universal here, and so frequently considered by us as being used but little on foreign engines, is not a distinctive feature of American construction. It is almost universal in Germany, and is frequently used in Great Britain, France and elsewhere. The plan of equalization is in general the same everywhere; it provides three points of support for the body of the engine, so that whatever be the position of the wheels vertically within about a 2½-in. limit, the weight on the wheels will not be materially different. Without equalization on a rough track it is possible to have an excessive weight on one pair of wheels. Generally the leading truck, or the leading pair of drivers when there is no truck, is taken as one of the points of support. The other two points of support are the resultants of the two equalizer systems, one on each side of the engine. Figs. 10, 11, 12, 13 and 14 show the more common methods adopted for equalization in this country.

When equalizers are not used, the weight distribution depends upon the adjustment of the spring hangers. When there is a pair of carrying wheels front and back of the drivers, as on some classes of

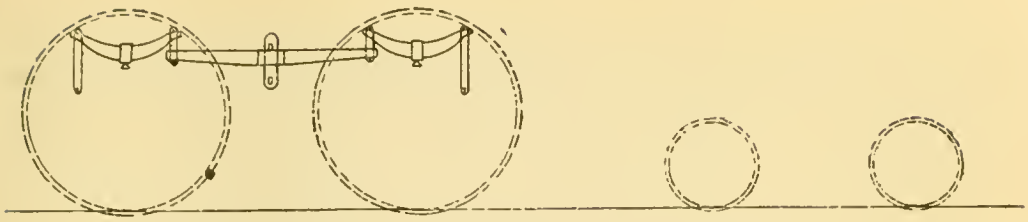


Fig. 10.
Equalizing system for American Eight-Wheel Locomotive.

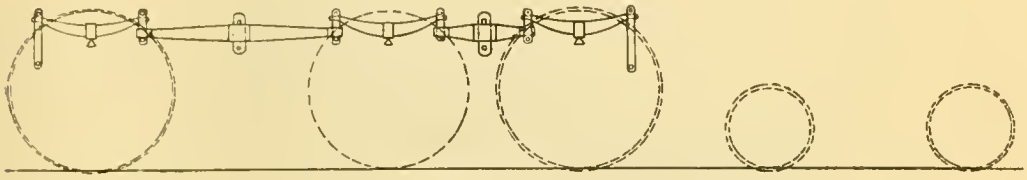


Fig. 11.
Equalizing system for American 10-Wheel Locomotive.

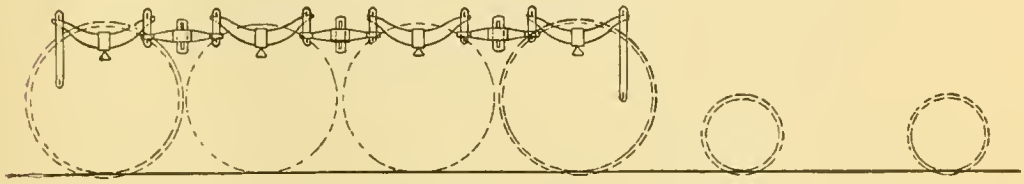


Fig. 12.
Equalizing system for American 12-Wheel Locomotive.

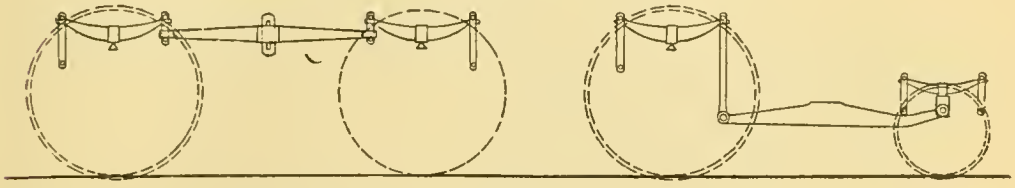


Fig. 13.
Equalizing system for American Mogul Locomotives.

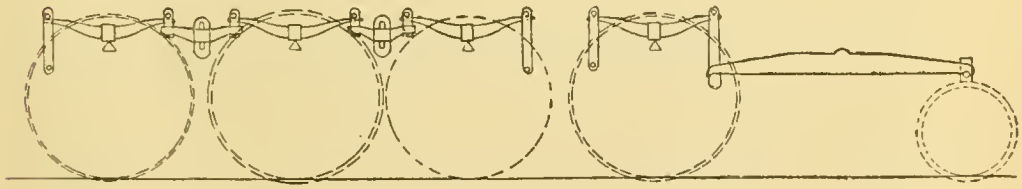


Fig. 14.
Equalizing system for American Consolidation Locomotives.

foreign locomotives, the weight on drivers can be changed greatly by changing the lengths of the spring hangers. The variation in weight on drivers that can in this way be produced is as much as 50 per cent. Of course, such changes can only be made by changing the weight on the trucks. If the springs are stiff, an equalization system is abso-

lutely necessary in this country, with its large percentage of uneven track, in order to prevent the hard riding of the engines and the breakage of springs ; but with long and flexible springs, there is less need for equalization. This appears from the analysis of the changes of weight on drivers accompanying various deflections of the track when the engines have stiff or flexible springs, as shown by Fig. 15.

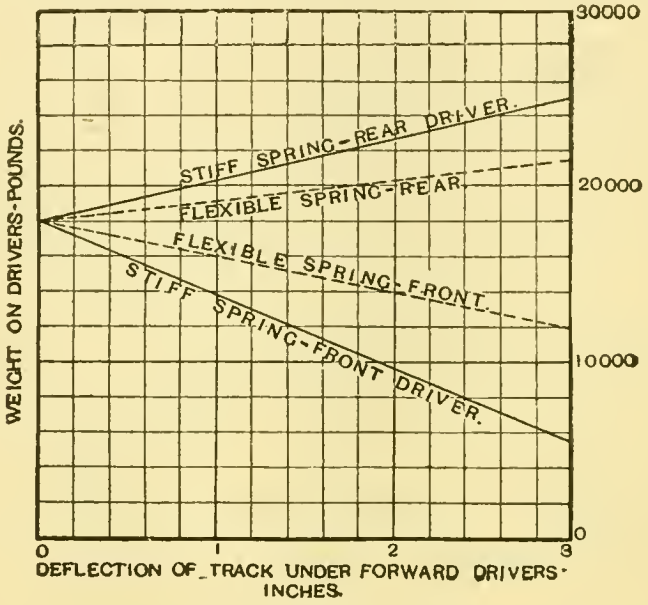


Fig. 15.

Diagram showing the change in weight on drivers of a four-coupled American eight-wheel locomotive produced by a deflection of the track when equalizers are not used between the coupled wheels.

Normal load on track per wheel = 18 000 lbs.
Stiff spring deflects 2 ins. with 13 000 lbs.
Flexible spring deflects 4 ins. with 13 000 lbs.

It will be seen from this diagram that a decided and abrupt change in the vertical alignment of the track produces much change in the distribution of weight on drivers when there are no equalizers, even when very flexible springs are used; and therefore in this country, where rail joints are liable to be low, the only way to keep an approximately uniform weight on drivers at slow speeds is to provide for equalization. It is impossible in this paper to enter upon a discussion of the common roughness of track in this country; yet it is best to say that the main track of the well-supervised roads here is quite sufficiently well kept up to permit engines to run without equalizers; but the sidings and the average track are in such condition as to demand an equalizing system to give durability to the springs and to prevent severe twisting strains on the axles and the breakage of crank pins by sudden changes of load.

It is a grave question whether the use of equalizers between the driving wheels of locomotives is best for the track joints; for example, if the locomotive with the weights assumed for Fig. 15, has equalizers and is run over a weak and low joint, that joint will be subjected to the full pressure on each driver, or 18 000 lbs.; but if the drivers are not equalized, the pressure on the joints depends

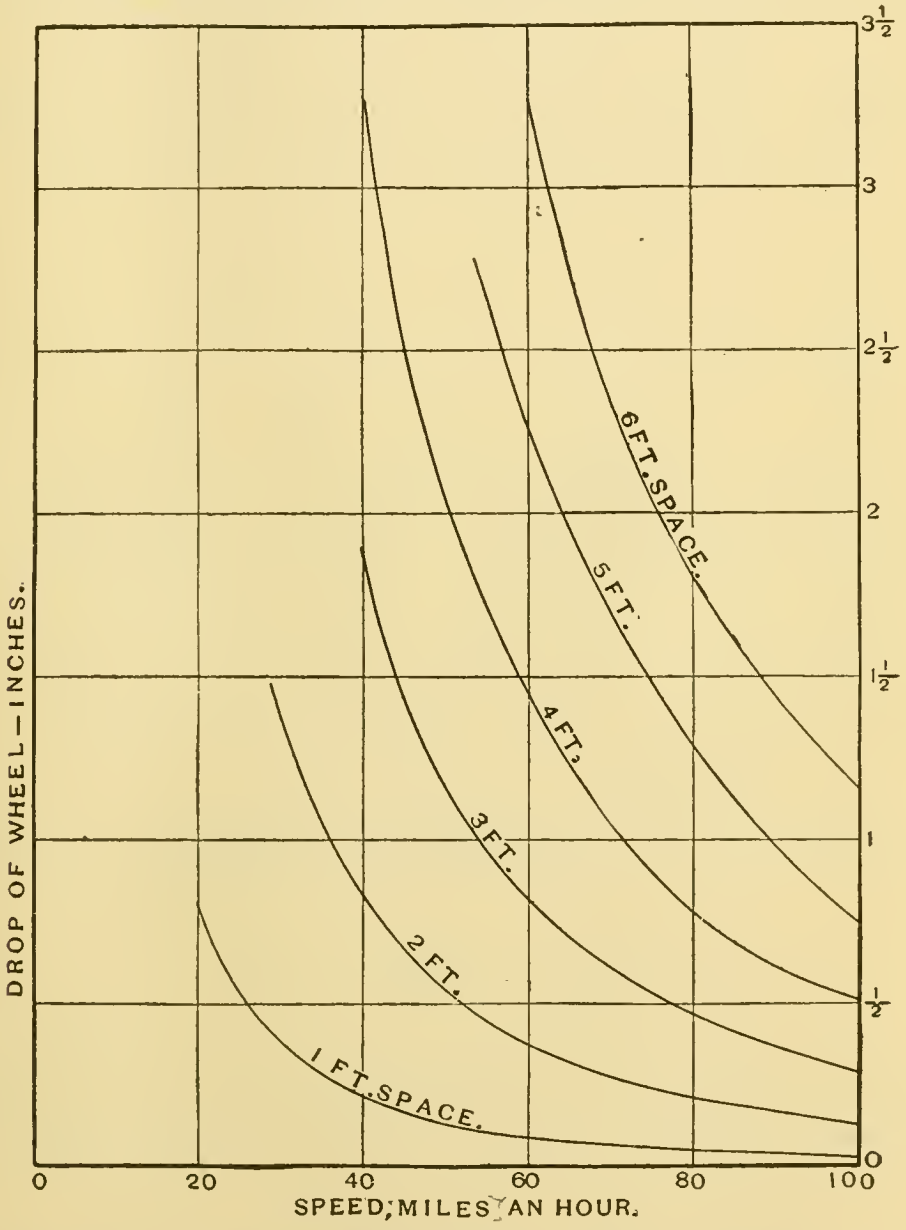


Fig. 16.

Diagram showing the distance that a locomotive driving wheel will drop or move downward by the action of gravity and the force of the spring above the wheel while passing over various spaces in the track at different speeds.

upon the deflection of the joints. If, with stiff springs over the wheels, the joints deflect as much as $1\frac{1}{2}$ ins., the load thereon would

be but 11 750 lbs. However, the foregoing is true only when the engine is moving slowly, and therefore only applies to the bad track common on sidings and in yards.

At speed the inertia of the driving wheels and their attachments resists any sudden downward movement of the wheel into a depression of the track. At 80 miles an hour, the time of passing the 2 ft. preceding a rail joint is about .017 second. The force of gravity and the force of the spring above the driver would cause the driver to move downward but about .206 in. in this interval (see Fig. 16), so that even if the statical load of the driver under normal conditions would cause 1 in. deflection of a joint, yet, owing to the inertia of the driver and its attached parts, the force of the spring above the wheel

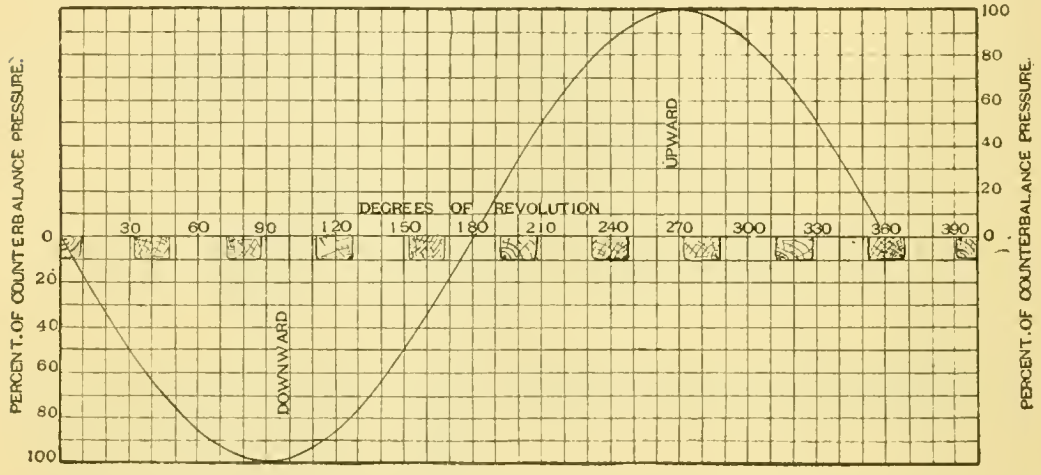


Fig. 17.

Diagram showing the percentage of the maximum counterbalance pressure on the track which is exerted at different points during a complete revolution of a locomotive driving wheel when the track is rigid and does not deflect under the load due to the counterbalance pressure.

and the action of gravity would only move the driver downward .206 in. Thus, while an equalizing system between driving wheels has the tendency to keep the weight on drivers uniform, and also throws a full load on a weak joint at low speeds, yet at high speeds the load is materially reduced by the inertia of the wheel and its parts, and the pressure of the wheels on the rail is by no means uniform, although the equalizers be provided. Also, at high speeds the variation in weight on the track produced by the counterbalance quite disarranges any distribution of weight that would otherwise come from an equalizing system. Figs. 17, 18 and 19 show that so far as the pressure of the wheels on the track at high speeds is concerned, much more depends

upon the rigidity of the track and the amount of counterbalance than upon the equalizing system.

Counterbalancing.—American locomotives ride easier than the foreign on account of the longer springs, the higher boilers, and the greater total weight. The counterbalancing, fore and aft, is quite perfect here, but more counterbalance is used; not more in proportion to the amount of the weight to be balanced, but more in total; the reason being that much less attention has been paid to the reduction of the weight of the reciprocating parts in the United States than in other

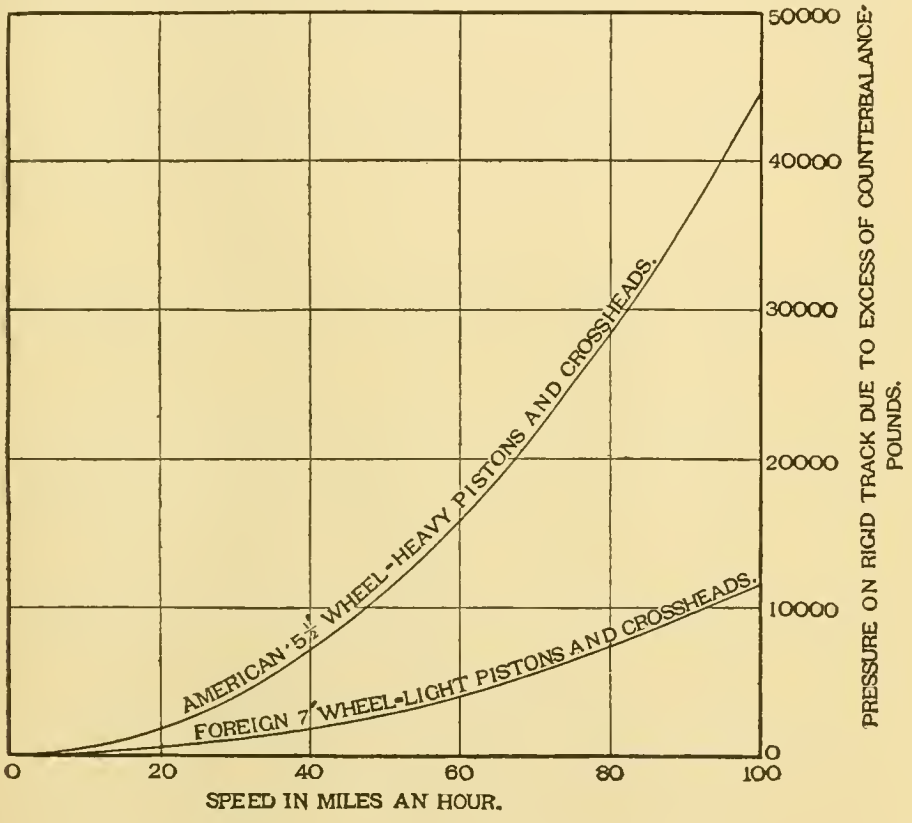


Fig. 18.

Diagram showing the maximum pressure on a rigid track due to that portion of the counterbalance of a locomotive that is used to counteract the horizontal effect of the reciprocating parts of American and foreign locomotives of the same size of cylinder. This diagram also illustrates the reduction of the variation of pressure of a driving wheels upon the track that follows an increase in the diameter of the driving wheels and a reduction of the weight of the reciprocating parts.

countries. Perhaps the reason is, that to reduce the weight of reciprocating parts beyond a certain limit entails a decided increase of cost; but whatever be the reason, one finds the weights of the pistons, crossheads, piston rods and connecting rods, heavier on engines in this country than in Europe. A fair estimate of the proportion of the

weights of these parts, as used here and in foreign countries, is as follows:

Foreign	1.
American	2.38

Recently more attention has been paid to the reduction of the weights of reciprocating parts of locomotives in the United States, and

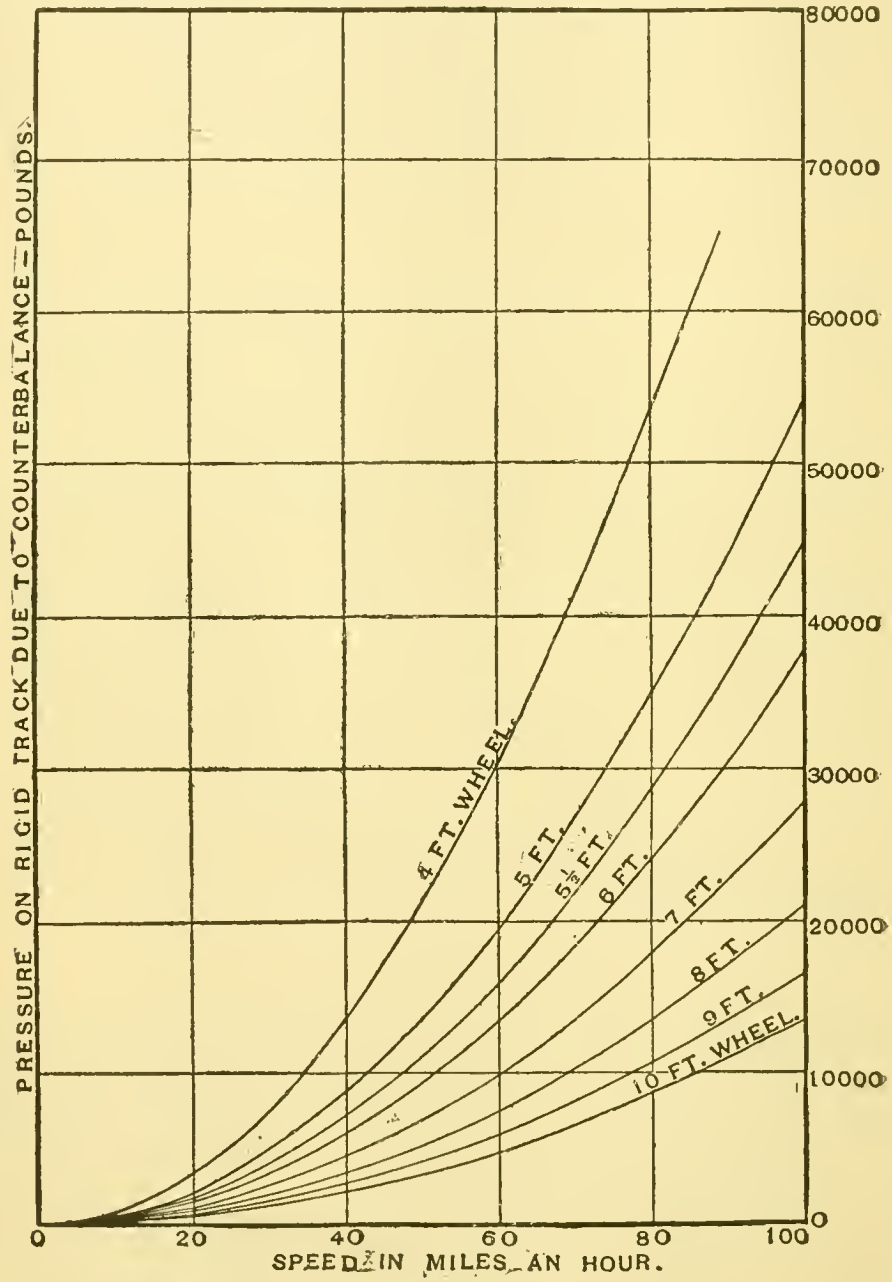


Fig. 19.

Diagram showing the decrease in the maximum track pressure, of that part of the locomotive counterbalance that is used to counteract the horizontal effect of the reciprocating parts, which accompanies an increase in the diameter of the driving wheels on the same engine with the same reciprocating parts, 18 x 24 in. cylinder.

a few of the latest designs have 25% less reciprocating weight to be balanced than is found in average American practice.

If there should be allotted to counterbalancing of locomotives the importance that is given it by some of our railroad track and bridge experts, it would, perhaps, be necessary to class the heavy reciprocating parts used here as a distinctive feature, and a bad one, of the construction of American engines. It is not uncommon for our track experts to advocate the removal of that portion of the counterbalance which is put in to counterbalance the reciprocating parts. Recently attention has been so strongly directed to this matter here that a step in advance has been promised, and light cast-steel and wrought-iron pistons are being talked of ; but the improvement proposed is small and does not give the light weight of reciprocating parts that is found in other countries.

It is not just to say that all American engines have such very heavy reciprocating parts as has been indicated here ; but as a rule American engines have these parts much heavier than is necessary, and this leads to the excessive counterweights, which have given ground for a just criticism of this feature of American locomotive design. For instance, some compound locomotives have been built in this country with a single piston weighing over 800 lbs. The builders did not realize at the time the result of this, and put in as much counterbalance as was necessary to make the engine ride well. The result was almost disastrous to the track at 60 miles an hour, the maximum pressure on the rail reaching nearly 50 000 lbs. per wheel. At this speed the wheels of this engine lifted from the rail when the counterbalance was up and seriously affected the track when the balance was down, as has been the case before both in this and other countries when engines have been overbalanced. In several instances, both here and abroad, short sections of track have been badly damaged by running overbalanced engines at high speed. In one case it was caused by running an engine with small wheels at high speed without the parallel rods.

The comparative effect of counterweights of some American, English, German and French high-speed locomotives is given in Fig. 19. This diagram, when read in connection with Figs. 15, 16, 17 and 18, shows how the distribution of the weight of a locomotive on the track is affected by the counterweight, and by the deflection of the rails when engines are moving at high speed. All

these matters so affect the limit of weight that is admissible on one driving wheel, that those who have to determine the limit for any given track need to make careful analysis of the detail designs of locomotives in order to reach safe conclusions. Such analysis is one of the duties of the railroad civil engineer, and in studying this problem, the long lengths of track over which is spread the downward action of the counterbalance, as shown by Fig. 17, must not be forgotten.

It has been shown that it requires time for a wheel to drop into a depression in the track, and how this materially affects the load on a weak joint, yet this statement needs modification to the extent that it is affected by the distance between the center of revolution and the center of gravity of the driving wheels. This distance is about 1.3 ins. for the wheel considered in the counterbalancing for an American engine, given in Fig. 18. A wheel will follow instantly any deflection of rail up to the amount of the distance of center of gravity from center of figure, and therefore on a track having such elasticity that it would deflect, under the additional load brought upon it by the counterweight, nearly as great a distance as that between the center of gravity of the wheel and its center of figure, there would be but little additional pressure brought on the rail by the centrifugal tendency of the counterbalance, the reason being that the wheel would then revolve nearly on its center of gravity, and would have, therefore, but little centrifugal tendency.

This is an example of the extreme condition, and only serves to illustrate more clearly the point now being made, which is that such deflection of the track as actually takes place on good roadbeds reduces materially the effect of the counterbalances. In this matter some have erred by assuming the whole centrifugal tendency that would exist if the wheel revolved on its center of figure, and the track did not deflect under the increased load. Such deflection of the track as actually does occur has a large modifying effect on the variation of pressure on the rail, caused by the centrifugal tendency of the counter-balance for the reciprocating parts. No doubt the flexible track used here has decreased considerably the damage that would otherwise have resulted from the use of heavy reciprocating parts if our track had been laid on a more rigid roadbed.

Centrifugal action is not, strictly speaking, a force, but is only a

tendency, and does not exist unless the wheel is constrained to revolve on a point outside of its center of gravity. In a large, heavy wheel, if the counterbalance be light, the distance from the center of gravity to the center of revolution is so small that the centrifugal tendency that would exist on a rigid track is greatly reduced on a comparatively flexible track.

Driving-Wheel Centers.—In this country driving-wheel centers are generally made of cast iron, with the tires held on by shrinkage alone. The Pennsylvania Railroad has had a few wrought-iron centers in use for several years ; the Chicago and Erie Railroad has quite a number of wrought-iron centers of the Vauclain type, and there are a few wrought drivers on other roads here; but, in general, a hard cast iron is used. In foreign countries the wrought-iron or cast-steel driving-wheel center is common practice, and tires are held on by retaining rings. The retaining ring, or some other auxiliary tire fastening, is necessary in addition to the security obtained from shrinkage of the tire when a wrought or light cast-steel center is used, owing to the deflection of the light center under the heavy stresses caused by shrinkage of the tire, and it is this which governs the use of retaining rings and other tire fastenings. Such wrought-iron centers as have been used here have had an auxiliary tire fastening, and where light centers are common, tire fastenings are common also. Cast-iron centers for wheels up to 6 ft. in diameter have been proved to be perfectly safe without auxiliary tire fastenings, and such centers are used in this country mainly on account of the low first cost. Wrought centers would do no better service than cast ones in our smaller wheels, and, therefore, it is doubtful if wrought-iron centers will ever be much used in this country for wheels less than 5½ ft. in diameter. One advantage of our heavy driving wheels is the reduction of the distance between the center of revolution and the center of gravity, and this tends to reduce the effect of the heavy reciprocating parts used here.

Tenders.—The foreign tender is generally of the type shown in Fig. 20, and the American of the type shown in Fig. 21. The American differs from the foreign mainly in the frames and trucks. In the American there are two trucks of the swiveling type. Lateral motion trucks are not generally used here for tenders. Taken altogether, the foreign tender appears to be more practical than the American, and the service trial of one with the Webb compound on the Pennsylvania road during

the past two years has led some of our railroad engineers to recommend an extensive trial of six-wheel tenders in the place of the eight-wheel, in order to gain, if possible, the greater simplicity and accessibility and the less weight of the foreign type.

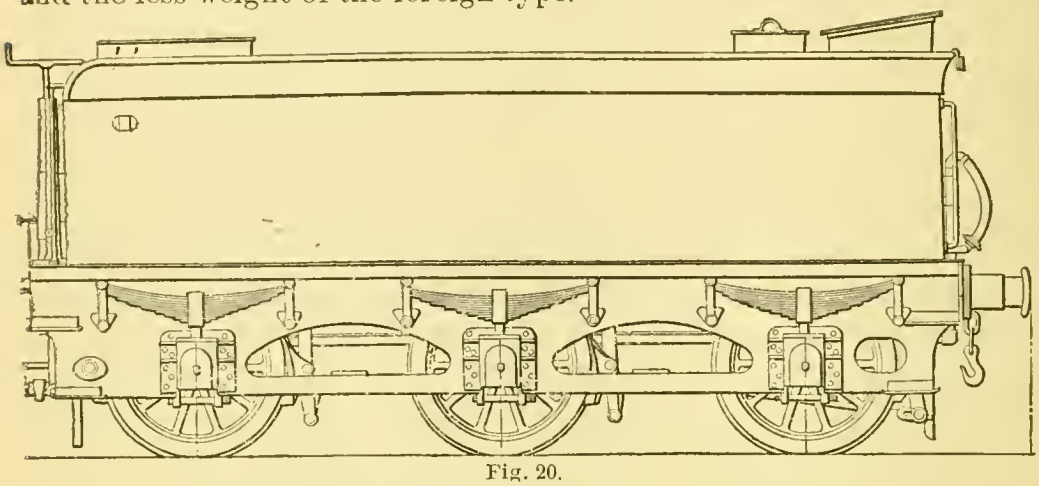


Fig. 20.
Foreign Tender.

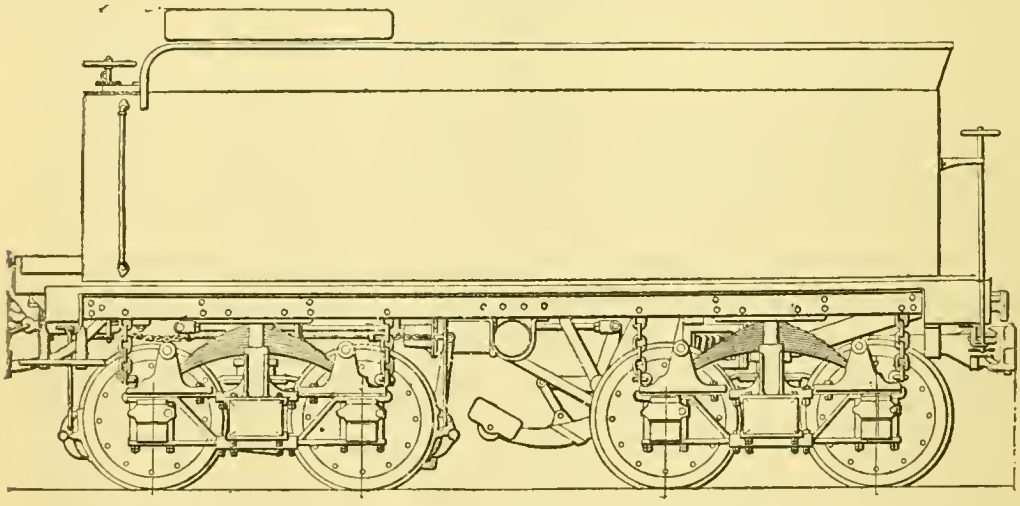


Fig. 21.
American Tender.

Method of Operation.—The forcing of American locomotives, which results from the necessary policy of hauling heavy train loads, is perhaps best illustrated by Fig. 7, which shows the decrease of the evaporation of water per pound of coal in a locomotive boiler which accompanies an increase in the coal "used" per square foot of grate per hour. The term "used" is perhaps better than "burned," because much of the coal that is thrown into a locomotive firebox is not burned, but goes through the tubes in the form of cinder and smoke. This diagram is taken from many results obtained within the last three years on American railroads, during locomotive tests, where

the coal used per square foot of grate per hour has varied from about 60 to nearly 200 lbs. That there is the marked decrease in evaporation accompanying an increase in the rate of coal used that is shown by the diagram is becoming well known here, and has recently led to a stronger conviction about the advantage of using large grate areas. In some recent tests of three locomotives, having different grate areas, it was found that the coal used per square foot of grate varied almost in an inverse proportion to the total area of the grates, and the water evaporated per pound of coal decreased with the increase in coal used almost exactly as shown on the diagram. This led to the conclusion at the time that the larger the grate that could be put on a locomotive the greater would be the evaporation per pound of coal used, provided always that the grate does not exceed in size that which can be properly handled by the firemen. In some cases we have made the grates too large, but as a rule a good fireman can properly fire a furnace with a grate not exceeding 10½ ft. in length, and up to this length it is practicable to go. On roads where a deep firebox with a comparatively small grate has been used for a long time, the firemen object strongly to the introduction of a shallow firebox and a larger grate, as it requires more skill and attention.

On the coal diagram, Fig. 7, there are three lines—one showing the evaporative power of Western American coal, such as is commonly used in the vicinity of Chicago and farther west; the next line gives a fair average of the coal used throughout the United States; the upper line shows the better quality of the best American and the average English coal. Perhaps the difference in the English and American coals is better illustrated by the points representing individual tests by Kennedy and Donkin, and the results obtained by Mr. Webb with the compound locomotive "Greater Britain." These points are considerably above the highest results from American locomotives using the best American coal (see the result obtained by Professor Goss during the Purdue University shop tests of a locomotive). The continuation of the upper line on the diagram from *A* to *B* illustrates the difference in the way in which locomotives are worked here and in foreign countries. It is not common, except in the United States, to use over 70 lbs. of coal per square foot of grate per hour. The difference between the evaporation per pound of coal used from *A* to *B* and that given on the line representing the average American coal, shows how much greater is

TABLE C.

Analysis of Coal Found in Various Parts of the Earth.

Country.	Location.	Commercial Name of Coal.	Fixed Carbon.	Volatile matter including carbon, hydrogen, oxygen, nitrogen, sulphur and other volatile substances except water.*	Ash.	Water.	Remarks.	Sulphur.
United States..	Connellsville, Pa.....	Broad Ford.....	59.616	30.891	8.233	1.26	Pennsylvania coking coals.....	0.784
" ..	" "	Coketon.....	65.72	22.55	11.71	....	" "	0.70
" ..	Irwins "	Pennsylvania gas coal	54.88	39.09	6.98	....	" " washed slack.....	0.96
" ..	Allegheny Mt. "	Barrington B.....	61.843	29.825	6.93	1.40	" "	2.60
" ..	" "	Lilly's Station E....	70.52	23.709	5.058	0.715	" "	1.459
" ..	Blossburg "	Arnot, Seymour vein	71.574	22.493	4.753	1.18	" " washed slack.....	0 907
" ..	Allegheny River, Pa.	Lower Freeport.....	54.223	37.137	7.34	1.30	" " "	1.312
" ..	Beaver County "	Hulmes & Brother...	54.619	38.901	4.080	2.40	" "	0.791
" ..	New River, W. Va...	Quinnimont.....	75.89	18.49	4.68	0.94	West Virginia " washed slack.....	0.30
" ..	" " ...	Fire Creek.....	75.02	22.90	1.47	0.61	" "	0.56
" ..	" " ...	Longdale.....	72.32	21.65	5.27	1.03	" "	0.27
" ..	" " ...	Nuttallburg.....	69.00	30.37	1.07	0.34	" "	0.78
" ..	Leetonia, Ohio.....	Washingtonville.....	56.04	40.13	1.80	2.56	Ohio "	0.53
" ..	Steubenville, Ohio..	Shaft coal.....	65.90	31.88	1.80	1.40	" "	0.98
" ..	Tracy City, Tenn....	Sewanee.....	61.00	29.30	7.80	1 60	Tennessee "	Trace.
" ..	Whiteside, "	Kelly	74.20	21.80	2.70	1.30	" "	0.70
" ..	Rockwood, "	Roanoke Iron Co.....	63.74	26.950	7.82	1.49	" "	0.330
" ..	Warrior Field, Ala...	Pratt seam.....	61.60	32.398	5.416	1.508	Alabama "	0.918
" ..	Cahaba, " ...	Helena.....	59.58	35.03	6.050	....	" "	0.66
" ..	Big Muddy, Ill.....	Mt. Carbon.....	59.13	32.69	1.81	6.37	Illinois "	0.76
" ..	El Moro, Col.....	El Moro.....	55.86	38.23	3.59	1.32	Colorado "	
" ..	Crested Buttes.....	Crested Buttes.....	72.60	23.20	3.10	1.10	" "	
" ..	Peru, Ill.....	Illinois.....	51.26	33.90	4.54	10.30	Rudy, 1878.	
" ..	Youghiougheny, Pa.	Youghiougheny.	66.85	28.90	3.35	0.90	Professor Weber.	
" ..	Briar Hill, Ohio.....	Briar Hill.....	62.66	32 58	1.16	3.60	" "	
" ..	La Salle, Ill..	Illinois.....	43.95	39.40	8.43	8.22	University of Illinois, 1889-1890. Clark.	
" ..	Peru, "	"	47.20	37.19	6.61	9.00	" "	
" ..	Bloomington, Ill....	"	45.20	35.99	14 71	4.10	" "	
" ..	Streator "	"	45 30	38.88	8.60	7 20	" "	3.30
" ..	Oakwood "	"	46.01	37.55	8.65	7.80	" "	
" ..	Fairmount, "	"	47.05	31.80	13.05	8.10	" "	
" ..	Danville, "	"	53.00	32.55	3.65	11.00	" "	
" ..	" "	" ...	45.37	43.70	6.15	5.78	" "	
" ..	" "	" ...	46.43	37.07	10.88	5.62	" "	
" ..	Lincoln, "	"	44.50	34.99	12.06	8.45	" "	
" ..	" "	"	49.50	31.30	11.70	7.50	" "	

" ..	Mt. Pulaski, "	" ...	46.53	35.82	9.97	7.68	" "		
" ..	Niantic, "	"	47.40	36 25	8.47	7.88	" "		
" ..	" "	"	45.50	34.15	8.50	11.85	" "		
" ..	Riverton, "	"	48.45	35.39	9.78	6.38	" "		
" ..	" "	"	44.30	38 45	6.15	11.10	" "		
" ..	Barclay, "	"	46.25	35.67	10.71	7.37	" "		
" ..	Pana, "	"	46.95	36.37	9.46	7 22			
" ..	Assumption, "	"	50.10	41.20	4.80	3.90	University of Illinois, 1889-1890. Clark.		
" ..	Mt. Olive, "	"	44.49	35.43	11.11	7.97	" "		
" ..	" "	"	51.50	35.00	8.20	5.30	" "		
" ..	Odin, "	"	50.86	33.99	9.08	6.07	" "		
" ..	Odin, "	"	46.90	41.10	6.10	5.90	" "		
" ..	Kinmundy, "	"	47.45	34.00	11.55	7.00	" "		
" ..	Sandoval, "	"	50.86	35.07	6.88	7.19	" "		
" ..	Centralia, "	"	45.50	38.18	8.04	8.28	" "		
" ..	Milwaukee, Wis.....	Braceville.....	45.30	40.05	8.95	8.82	Av'ge of 17 analyses. C.M.& St.P.R.R. Gibb's,'92.		3.12
" ..	" "	Pittsburgh.....	53.22	39.59	6.88	1.99	" "	"	1.68
" ..	Pittsburgh, Pa.....	Monongahela, Gas....	.....	35.74	6.66	....	Thurston.		
" ..	Bloomington, Ill...	Illinois.....	53.12	34.02	4.96	7.90	Rudy, 1878.		
" ..	Briar Bluff, " ..	"	48.54	28.96	9.90	12.60	"		
" ..	Barclay, " ..	"	44.78	27.32	17.10	10.80	"		
" ..	Carbondale, " ..	"	59.84	26.40	7.40	6.36	"		
" ..	Catlin, " ..	"	48.42	31.08	12.70	7.80	"		
" ..	Danville, " ..	"	31.20	.....	14.64	9.60	"		
" ..	Du Quoin, " ..	"	60.60	23.54	7.00	8.86	"		
" ..	Elmwood, " ..	"	55.30	27.60	9.50	7.60	"		
" ..	Farmington, " ..	"	50.48	29.28	11.72	8.52	"		
" ..	Grape Creek, " ..	"	51.32	28.34	10.60	9.74	"		
" ..	Kewanee, " ..	"	49.66	27.60	7.14	15.60	"		
" ..	Lincoln, " ..	"	46.64	27.60	14.84	10.92	"		
" ..	Lombardville, " ..	"	51.74	31.38	7.46	9.42	"		
" ..	Mt. Carbon, " ..	"	66.50	24.68	2.70	6.12	"		
" ..	Oglesby, 2d vein," ..	"	49.32	30.84	7.72	12.12	"		
" ..	" 3d " " ..	"	55.88	30.34	3.72	10.06	"		
" ..	Du Quoin, " ..	"	53.69	32.03	7.44	6 84	University of Illinois, 1889-1890. Clark.		
" ..	" " ..	"	54.08	30.35	8.90	6.67	" "	"	
" ..	Big Muddy, " ..	"	56.00	32.15	4.00	7.85	" "	"	
" ..	Carbondale, " ..	"	57.50	33.65	4 60	4 25	" "	"	
" ..	Youghiougheny, Pa..	Youghiougheny.....	60.82	33.13	4.65	1.40	" "	"	
" ..	" " ..	"	58.10	35.80	5.40	0.70	" "	"	
" ..	La Fayette, Ind.....	Brazil Block.....	48.78	32.34	5.81	13.05	Purdue University. W. F. Goss.		
Great Britain..	South Wales.....	.....	88.3	8.5	3.2	....	Slightly bit. Steam coal. Wilson		1.8
" ..	"	.....	92.3	6.2	1 5	....	Anthracite. No smoke.		
" ..	Wales	.....	83.78	11.35	4.91	....	Haswell's 3d ed., p. 566, 1879.....		1.43
" ..	Lancashire, Eng.....	.....	82.6	15.90	1.5	....	Semi-bit. steam coal. Much smoke.....		0.8
" ..	Lancashire, Eng.....	.....	80.1	17.20	2.7	....	Bit. gas coal.....		1.5
" ..	Derbyshire.....	.....	79.9	17.7	2.4	....	Semi-bit. house and gas coal.....		0.7

* These substances are frequently taken together as "combustible volatile matter."

TABLE C—(*Continued*).

Country.	Location.	Commercial. Name of Coal.	Fixed Carbon.	Volatile matter including carbor, hydrogen, oxygen, nitrogen, sulphur and other volatile substances except water.*	Ash.	Water.	Remarks.	Sulphur.
Great Britain..	Scotland.....	.....	80.1	17.5	2.4	....	Semi-bit. steam coal.....	1.4
" ..	"	.....	63.1	17.1	19.8	....	Bit. Boghead cannel gas coal.....	1.0
" ..	"	.....	78.53	17.41	4.03	....	Haswell's 33d ed., p. 566, 1879.....	1.11
" ..	England.....	Busty Seam, N.E.Eng.	81.22	14.96	3.28	0.85	Upper part of seam coking coals.....	0.81
" ..	"	" "	78.46	15.07	6.17	0.99	Lower " "	1.83
" ..	"	Brockwell Seam, "	83.40	12.58	3.50	0.90	Brockwell seam "	
" ..	"	Newcastle.....	82.10	13.6	3.50	....	R. H. Thurston. Composition of foreign coals..	1.2
" ..	"	Lancashire.....	77.90	17.5	4.60	....	" " "	1.4
" ..	"	Derbyshire.....	79.70	17.6	2.7	....	" " "	1.0
" ..	"	Staffordshire.....	78.6	20.4	1.0	....	" " "	0.4
" ..	Duffryan.....	.....	88.26	8.54	3.26	....	Haswell's 33d ed., p. 566, 1879.....	1.77
" ..	Cumberland, Eng....	.....	93.81	4.59	1.6	....	" "	
" ..	Northumberl'nd, Eng.	.....	84.3	14.96	0.7	....	Semi-bit. house coal. Wilson.....	1.2
" ..	and	.....	82.4	14.70	2.9	....	" steam "	1.3
" ..	Durham.....	.....	86.8	15.05	1.1	....	" coking "	0.9
	Vancouver Island....	.....	66.93	17.24	15.83	....	Haswell's 33d ed., p. 566, 1879.....	2.2
South America.	Chili, Conception Bay.	.....	70.55	21.93	7.52	....	" "	1.98
"	" Chiroqui.....	.....	38.98	24.11	36.91	....	" "	6.14
"	"	.....	70.6	22.0	7.4	....	R. H. Thurston. Composition of foreign coals..	2.0
"	Patagonia.....	.....	62.25	24.35	13.4	....	Haswell's 33d ed., p. 566, 1879.....	1.13
"	Brazil.....	.....	57.9	40.5	1.6	....	R. H. Thurston. Composition of foreign coals.	
Europe	France.....	.....	84.0	14.	2.0	....	" " "	
"	Spain	.....	53.0	40.	7.0	....	" " "	
"	Germany.....	Silesia.....	57.9	42.	2.1	....	" " "	
"	Saxony, Germany....	.....	80.0	19.	1.0	....	" " "	
"	Prussia, "	.....	56.7	18.9	24.4	....	" " "	
Asia.....	Hindoostan.....	.....	50.0	35.4	14.6	....	" " "	
"	Formosa Island.....	.....	78.26	17.78	3.96	....	Haswell's 33d ed , p. 566, 1879.....	0.49
Canada.....	Nova Scotia.....	.....	60.7	26.8	12.5	....	R. H. Thurston. Composition of foreign coals.	
"	Cape Breton.....	.....	67.6	26.9	5.5	....	" " "	
Australia	.....	Lignite.....	64.3	15.8	10.0	....	" " " ..	0.6
"	Sydney, S. Wales.....	.....	82.39	14.98	2.04	....	Haswell's 33d ed., p. 566, 1879.....	0.07
Borneo	.....	.....	70.3	26.5	14.2	....	R. H. Thurston. Composition of foreign coals...	1.2
Australia.....	Van Diemen's Land..	.....	63.4	6.16	30.45	....	Haswell's 33d ed., p. 566, 1879.....	0.98
"	S. Cape Aar'te B.....	.....	80.22	11.11	8.67	....	" "	1.90

* These substances are frequently taken together as "combustible volatile matter."

the efficiency of boilers operated without forcing than under the American plan of operation. The average evaporation per pound of coal used throughout the United States is not over 5½ lbs. of water from and at 212°, while that in foreign countries, when operated between the limits *A* and *B* on the diagram, and which is taken to be the average work, is nearly 10 lbs. These figures correspond to a considerable difference in coal used per square foot of grate per hour ; namely, 150 lbs. for the American and about 50 for the foreign.

There is such a wide difference in the evaporating power of the coals found in various parts of the earth, that a comparison of the performance of locomotives using different fuels is well-nigh impossible without a full knowledge of the chemical composition of the fuel used and a practical knowledge of its mechanical action in a locomotive firebox. Coals having much moisture and a large percentage of ash made up of fusible silicates do not give results in evaporation that would be expected from an examination of the chemical composition ; and coals having the same percentage of hydrogen, carbon, oxygen, etc., do not necessarily give the same results in evaporation ; hence, a practical knowledge of the value of various fuels in locomotive boilers is absolutely necessary before a fair comparison can be made of the relative performance of different engines under otherwise equal conditions.

The varieties of coal in common use and the wide difference in composition may be seen from Table C, but, unfortunately, the real value of the fuels in practical operation cannot be learned from this table, owing to the lack of data recorded by the different experimenters. What is lacking is the real evaporative power of the fuel under equal conditions, and there is much merit in the proposition recently made by one of our engineering societies, to establish a central testing station, with a standard boiler operated under standard conditions, for the purpose of determining the relative value of various fuels.

Perhaps Fig. 7 illustrates as well as need be the reason for the greater economy of foreign locomotives under the conditions of average operation. Of course, if the foreign engine were to be forced so much that the coal used per square foot of grate would increase from 50 to 150, the evaporation would drop from 10 to about 7½ ; and if the coal used on English engines were no better than that used here, the evaporation would certainly drop to less than 6 lbs. of water per

pound of coal, the same as for the American locomotive. Although there is evidently a waste of coal on the American plan of operating locomotives, yet, as has been shown in the discussion of Fig. 1, there is a gain to the railroad company by doing this. Perhaps the following approximate estimate made up from such accurate data as is now available will give a sufficiently close comparison of the coal used in the best foreign and the best American passenger train service, average coal being taken in both cases :

TABLE D.

Country.	Total train. Weight tons.	Coal per ton mile of total train.	Coal used per square foot grate per hour.	Water evaporated per pound of coal from 212° Fahr.	Coal per ton mile of passenger cars.
Foreign.....	220	.12 lbs.	60 lbs.	9½ lbs.	.182 lbs.
United States...	400	.15 "	110 "	6½ "	.191 "

This comparison shows how little is the difference in the weight of coal used per useful ton-mile here and abroad, under about the same conditions, even when no allowance is made for the difference in the quality of the coal. What this difference in quality amounts to can be seen by an inspection of Fig. 7, on which lines are drawn for the average American and average English coals. With the same coal for both typical locomotives, the American practice of heavy train loads would result in less coal per useful ton mile. In the United States, wages and train expenses other than for coal are so comparatively great as to leave no choice in train practice, and railroads are compelled to condense the passenger traffic into heavily loaded passenger trains run at long intervals in order to pay expenses. There are a few cases here where lighter trains than the average can be run with profit, such as between New York City and Philadelphia; but even there the trains must be heavier than the average foreign train, as more passengers must be carried per train to pay the greater cost of wages and other train expenses. Where parlor and sleeping cars are run, the greater weight of train per passenger also causes heavier train loads. This is seen from Table E.

TABLE E.

GIVING APPROXIMATE DEAD WEIGHT OF CARS PER PASSENGER.

Country.	Type of car.	Number of wheels.	Weight of empty car with trucks.	Number of seats for passengers per car.	Dead weight of car per pass.	Dead weight of cars, locomotive and tender per pass. if seating capacity is taken up.
Foreign.....	.....	4 or 6	30 000	30	1 000	1 538.5
United States..	Sleeper	12	100 000	28	3 571.4	5 312.5
" "	Day coach	8	56 786	62	913.0	1 702.2

There are many other conditions in this country that compel heavy passenger as well as heavy freight trains, and particularly is this true for through trains where the distances are long and the trains cannot be run frequently. Each modern train has a dining car, a baggage car, and frequently one or two mail cars in addition to the cars for passengers. Frequent light trains would not be possible, owing to the great distances between towns and the lack of traffic to pay for the greater cost of train expenses. It is necessary on most roads, in order to regain the cost of running passenger trains, to limit the number of trains and compel the public to wait until the end of business hours, or until railroad connections give a probability of a train load of passengers. Thus it is found in the West that trains leave principal cities mostly at night after business hours. Heavy trains being a necessity, it follows that locomotives must have great starting power, and this has confined American passenger engines to comparatively small wheels.

Small Drivers for Express Service.—We have been frequently criticised severely for the use of 5 and 5½-ft. drivers for express passenger work, but we have no choice. Take, for instance, a 400-ton train to be hauled out of a city like Chicago, having many grade crossings and grades of from 1 to 1½% on the main line on which the train may be stopped. The only possibility of hauling such trains and making the necessary local stops is by using a small wheel and a very powerful engine. When these heavy trains are at speed the resistance is less, as the inertia has been overcome, and not so much weight is thereafter needed on the drivers. After one of our heavy trains is accelerated to speed, a locomotive with 8 or 9-ft. drivers could keep it in motion and

accelerate slowly to a higher speed with greater economy than our present engines ; but as we are compelled to use the small drivers in order to start trains and accelerate them, there is no recourse but to use them even for very high-speed locomotives. The maximum rate of acceleration of one of our heavy trains (494 tons) is given in Figs. 22 and 23.

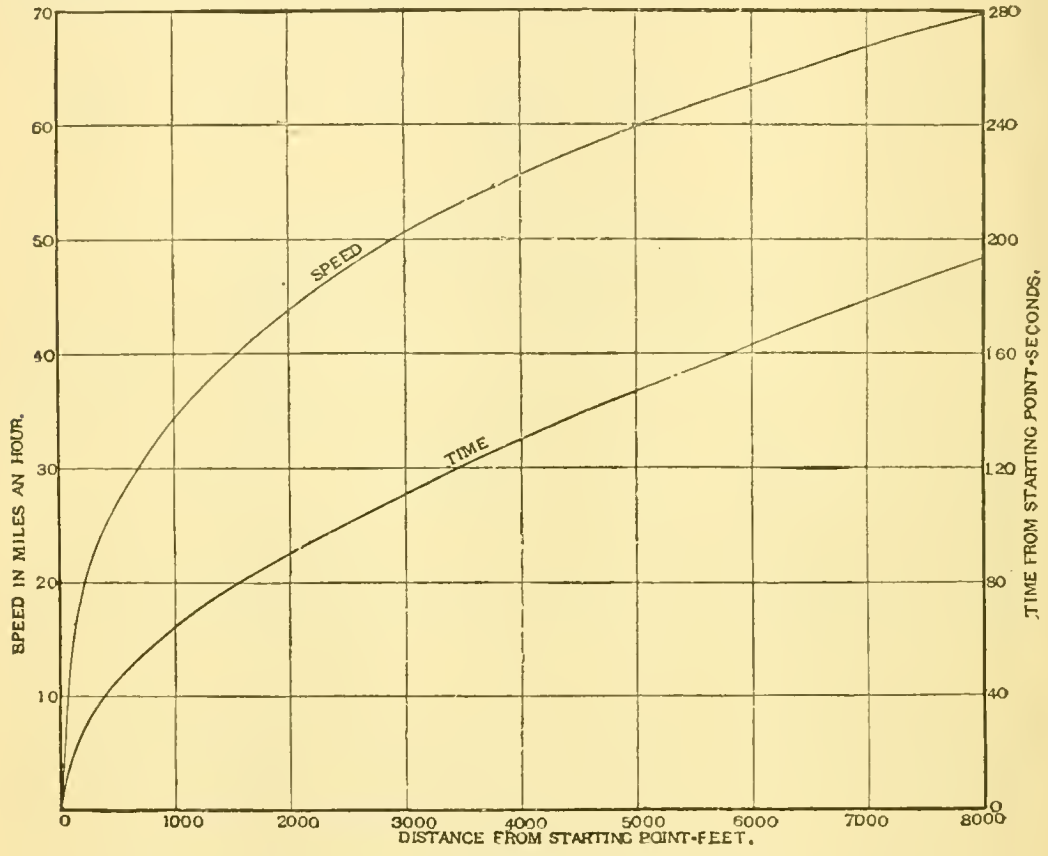


Fig. 22.

Diagram showing the maximum acceleration at different distances from the starting point of an American train of 494 tons, including the locomotive and tender.

The Empire State Express on the New York Central is a good example of the design of locomotive that is compelled by the conditions of operation existing in the United States. This locomotive weighs 64 tons, of which 40½ tons are on the drivers. The wheels are 6½ ft. in diameter and the cylinders 19 × 24 ins. This engine has very much more weight on drivers than is needed to furnish adhesion to haul the train when at high speed ; but even with the five-car train, which is the usual load for this engine, there is none too much boiler and cylinder power and weight for use during the accelerating period after leaving stations and to start the five-car train quickly when stopped

on a grade. In any other country wheels at least 8 ft. in diameter would be used for the fast work performed by this engine.

One of the most important factors affecting the size of drivers in the western section of the United States is the necessary policy (for economy) of pooling the heavy passenger engines with the freight engines. This pooling plan contemplates the use of all locomotives in freight service whenever it is advantageous to do so; hence a locomotive may haul a fast passenger train westward for 300 miles and return with a slow and heavy freight or with a through freight on a passenger train schedule. On some roads this pooling plan for engines governs the size of the drivers, as large drivers cannot be used in slow freight service.

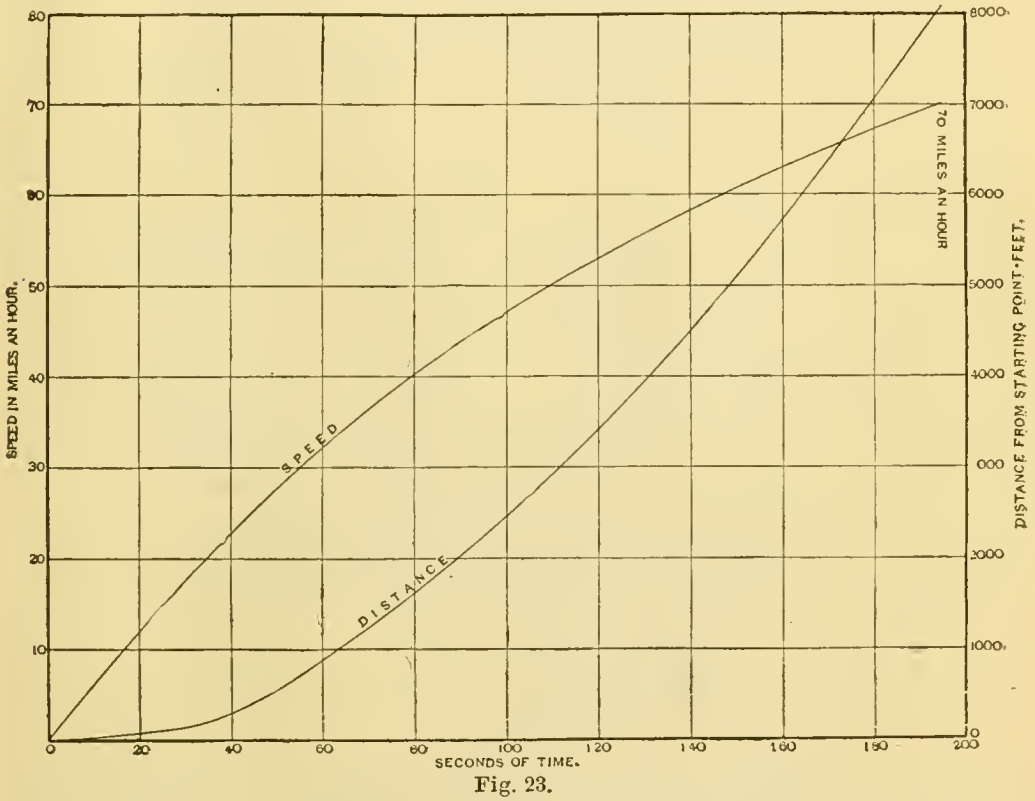


Fig. 23.

Diagram showing the maximum acceleration after different periods of time from the starting point of an American train of 494 tons, including locomotive and tender, when hauled by an American 10-wheel or Mogul locomotive with 47 tons on drivers and when equipped with the most improved valve motion.

To gain adhesion in starting trains, we have been urged to use the sand blast, but no material advance has been made here with that device, not so much from a lack of appreciation of the true value of a sand blast as from the fact that when our engines have boiler power enough to haul our heavy trains with comparative economy there is

found to be sufficient weight on drivers to start the trains without the need of a sand blast, excepting with a slippery rail, and that is provided for here by the sandboxes used. However, the sand blast is more effective than the ordinary sandbox arrangement, and we may expect that future locomotives for higher speeds than are now common in this country will have larger wheels and cylinders than our present types; and will be supplied with the sand blast, if necessary, to give greater adhesion at starting. For high-speed work we shall eventually be compelled to pay more attention to the decrease of total weight of engine and tender to increase the useful train weight ; light trains, large wheels and track tanks for water supply are the most necessary conditions for exceedingly high speeds.

The advantages of large driving wheels are well understood here, and much larger wheels would be used if it were practicable to do so. One of the main advantages of a large wheel is the better action of the valve motion. Perhaps this is best shown by Fig. 24, which

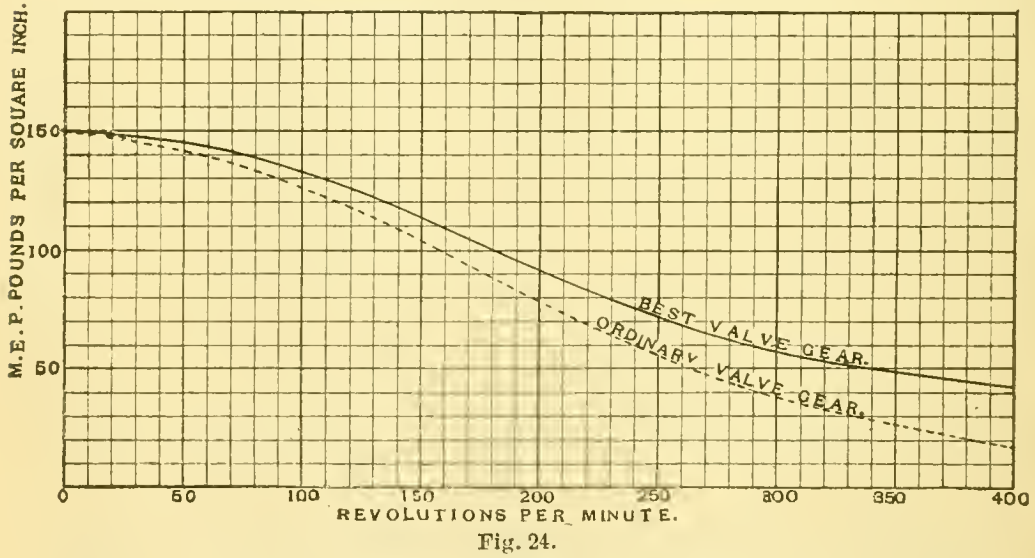


Fig. 24.

Diagram showing the decrease in the maximum mean effective pressure per square inch of piston, with the best and the ordinary valve gears, which follows an increase in the number of revolutions per minute of locomotive driving wheels. Boiler pressure, 175 lbs. per square inch absolute.

gives the reduction of the mean effective pressure in the cylinders of locomotives which accompanies an increase in piston speed. The full line shows the greatest mean effective pressure that has been obtained in any locomotive in this country with a 5½-ft. wheel, with a boiler pressure of 160 lbs. per square inch. This line has been drawn from the results obtained from some indicator cards taken with a special

valve motion which gave a wide opening to the steam port and a very late closing of the exhaust. It practically corresponds with the results obtained on the Reading road with large ports and 7-in. valve travel and 1¼-in. outside lap. The dotted line shows the decrease in the mean effective pressure with the ordinary proportions of Stephenson's link motion used in this and other countries. The variation in mean effective pressure at different speeds resulting from different designs of valve motion is given by the difference between the dotted and full lines. The decrease in the maximum mean effective pressure which accompanies an increase in speed has more bearing upon the possibili-

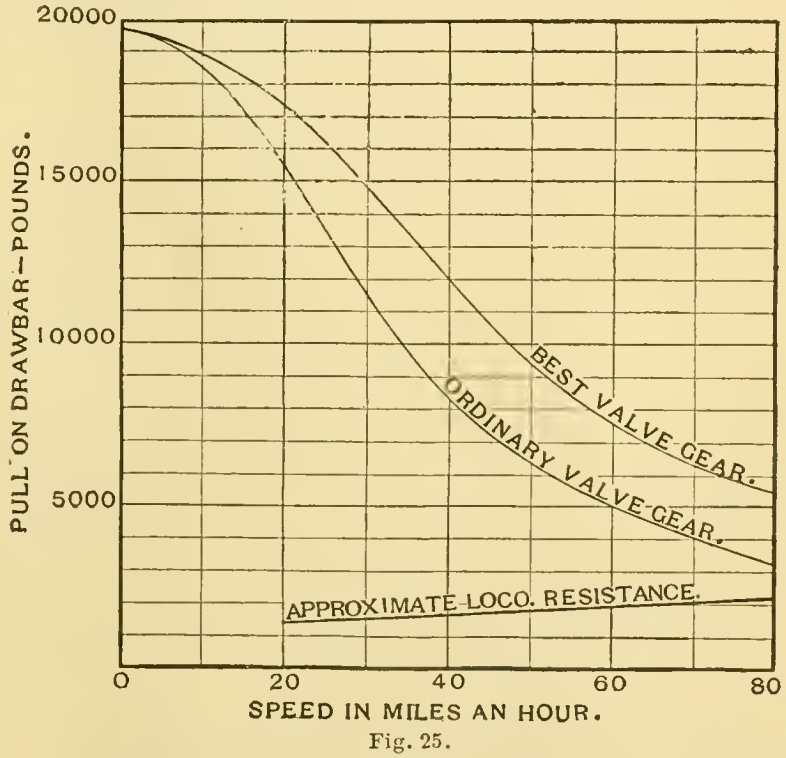


Fig. 25.

Diagram showing the decrease in maximum pull on drawbar which follows an increase in speed of a locomotive with 19 x 24 in. cylinders and 5½-ft. driving wheel.

ties of high speed than any other feature of locomotive design. Even the difficulty of supplying steam for high-speed work has not so much bearing upon the highest attainable velocity of railroad trains as this continual decrease of mean effective pressure. By using large boilers and the best fuel, sufficient steam can be generated to propel trains easily at 100 miles an hour, but it is exceedingly difficult to get a valve motion that will give enough mean effective pressure at 100 miles an hour to overcome the resistance of even a very light train. This is not the result of any material increase in the train resistance

at high speed, but arises almost solely from the reduction of cylinder power caused by the inadequacy of the valve gear and cylinder apparatus to maintain the same propelling power at high speed that is readily produced at moderate speed.

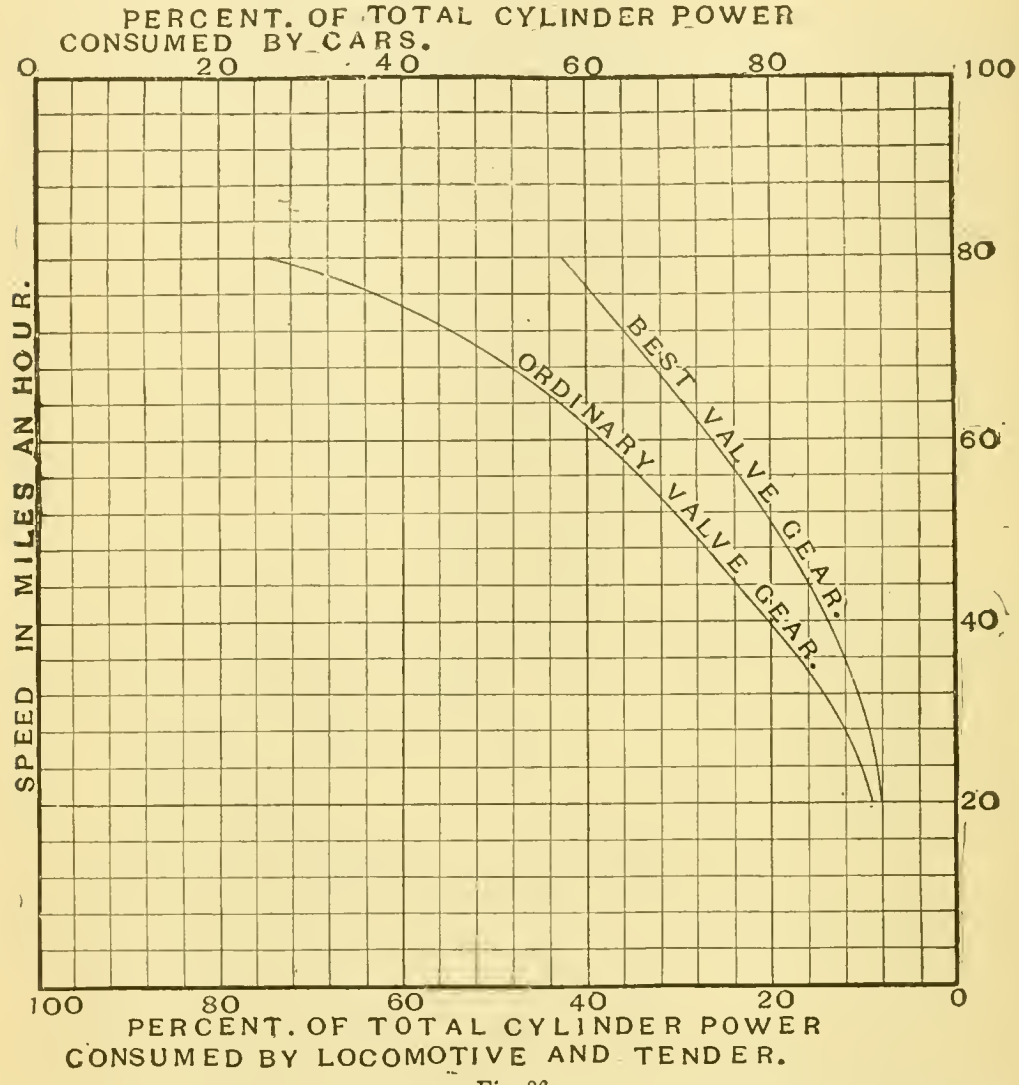


Fig. 26.

Diagram showing the increase of the percentage of cylinder power consumed by locomotive and tender which necessarily follows an increase of speed independent of any change there may be in train resistance.

Fig. 25 shows the decrease of hauling power as the speed is increased, both with the best and the ordinary valve gear. Fig. 26 shows the percentage of the power used by the locomotive and tender and that remaining to haul the cars at different speeds. This shows clearly that the rapid decrease of the power available for hauling cars is the prime cause of the difficulty of running heavy trains at high velocity. It is not, as has been claimed, caused by the rapid increase

in the resistance of the train resulting from head air resistance, suction of air at the rear, concussion, oscillation and other unimportant factors.

With a given valve motion, the speed in revolutions per minute almost wholly controls the highest attainable mean effective pressure in the cylinders. The greater the revolutions per minute, the less will be the mean effective pressure; hence the logical conclusion is that a larger driving wheel should be used for high-speed work. The effect of large driving wheels on the mean effective pressure is emphatically shown by Fig. 27, on which are drawn curves, indicating the

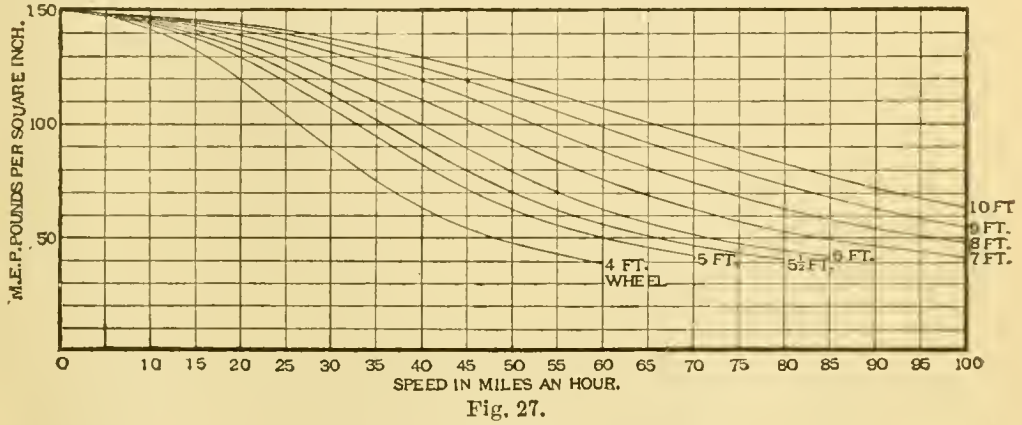


Fig. 27.

Diagram showing the maximum mean effective pressure on piston at various speeds that can be obtained with different diameters of driving wheels when steam valves are controlled by any of the existing types of link motion. Boiler pressure 175 lbs. per square inch (absolute).

variation of mean effective pressure at different speeds with different wheel diameters. From this, one would say immediately, Why not use 10-ft. drivers? But the answer comes at once; it is impossible to do so under conditions of American railroad operation except for special trains on which a large extra fare can be charged. The cost of running such a train as could be hauled by a locomotive having drivers 10 ft. in diameter is as great as the cost of running a slower one with many more cars, and the consequential cost of side-tracking freight trains and slower passenger trains is very great; and these, taken together with the greater risk of serious collisions, show why it is practicable only in a very few special cases, if any, to run trains in this country at a speed that would require 10-ft. drivers. Therefore, great as the advantages in steam use might be with larger drivers, the necessarily heavier loads in this country at the present time compel the smaller wheel.

Small drivers for high speed is a marked feature of American locomotive practice, and one that has many advantages in a new country

with long distances. The maximum speeds here are as high as in any other country, and the maximum average speeds for long distances are higher here than anywhere else, but we have not the same number of fast trains in proportion to the total number of trains as in England, but have more than the average on the continent of Europe. At the present rate of development of train service between New York and Chicago, the fastest and heaviest passenger trains on earth will be run in the United States ; but we have much to do in the development of locomotive design before the most practical locomotive for such service will be had. Larger wheels and cylinders, higher steam pressure and less dead weight of engine and tender, will probably be the lines that will be followed in gaining the best locomotive for this service.

Compound Locomotives.—American compound locomotives are almost exact counterparts in the compound features of those used in Europe, the single exception to this being the Vauclain and the Johnstone types. More than 400 of the Vauclain type have been built by the Baldwin Locomotive Works. So far, no marked advantage in fuel saving has been obtained from the use of compounds in this country in fast passenger service. This arises from the bad action of the valve motions used, it being more difficult to design a suitable steam regulating mechanism for compound locomotives on account of the greater back pressure in the high-pressure cylinder, particularly when small drivers are used. In freight and suburban service, where the single-expansion engine uses steam with less expansion than in faster work, the compounds of all types have given a reduction of from 12 to 40% in fuel. At this time, the development of the compound locomotive is so rapid that what is now a true general statement may within a year's time be shown to apply only to the narrow limits of present designs.

Duplication of Parts.—The cost of labor in the drafting room, the need of quick deliveries and the prevailing practice of contracts with individual mechanics, puts a premium on duplication and interchangeability of parts, and the result is that the locomotives of each prominent manufacturer in this country have many duplicate parts and dimensions, even when the general dimensions of the engines differ widely. This practice leads to low first cost and rapid construction, and to some extent aids in the universal endeavor to gain simplicity. The defect of it is found in the temptation to use too small details for the larger engines, and too large parts for the smaller ones. However

TABLE A1.

Giving Dimensions of American Locomotives.

Name of Railroad Company.	Number of drivers.	Number of front truck wheels	Number of rear truck wheels	With or without separate tender.	Inside or outside cylinders.	Single expansion or compound.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Total weight on driving wheels. Pounds.	Total weight on trucks. Pounds.	Weight of tender loaded. Pounds.	Area of Grate. Square feet.	Firebox heating surface. Square feet.	Tube heating surface. Square feet.	Diameter of shell of Boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure per square inch atmospheric. Pounds.	Length of tubes. Feet and inches.	Diameter of tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Coal capacity. Tonnds.	Ratio of cylinder power to weight, available for adhesion.
																			Ft. Ins.					
C. M. & St. P.	4	4	0	With	Outside	Single Expansion	62	16 x 24	86 000	54 000	32 000	65 000	15.5	115.	801	43	Wagon.	160	11 0	2	Passenger	3 200	10 000	0.461
New So. Wales	6	4	0	"	"	"	61	21 x 24	130 000	97 500	32 500	72 000	24.9	195.	1 821.5	62	Straight	160			"	3 600		0.447
C. R. R. of N. J.	4	4	0	"	"	"	68	19 x 24	105 200	75 900	30 000	(41 000 Empty) (35 100 Empty)	37.				Wagon	160	11 9½	2	"			0.421
B. & O.	6	4	0	"	"	"	62	21 x 26	133 000	103 300	29 700	76 800	28.2	188.5	1 846.8	64	"	160	13 2½	2¼	"			0.450
C. C. C & St. L.	6	4	0	"	"	"	66	18½ x 24	131 400	102 800	28 600	76 800	18.2	147.	1 883.4	60	"	160	13 4½	2	"	3 700	14 000	0 304
Penn. R. R.	4	4	0	"	"	"	78	19 x 24	123 000	81 000	42 000	87 050	26.2	144.3	1 672.2	58	"	180	12 0	2	"	3 500	16 000	0.387
N. Y. C. & H. R.	4	4	0	"	"	"	84½	19 x 24	123 000	82 200	40 800	80 500	27 3			58	"	180	12 0	2	"	3 587	14 500	0.352
C. B. & Q.	4	4	0	"	"	"	68	18 x 24		66 600			21.5	111.	1 301	56	Straight	160			"			0 426
N. Y. C. & H. R.	4	4	0	"	"	"	78	19 x 24	126 150	81 400	44 750	81 720	27.3	147.7	1 670.7	58	Wagon	180	12 0	2	"	3 500	13 500	0.385
C. C. C. & St. L.	4	4	0	"	"	"	68	18½ x 24	129 280	86 500	42 780	85 280	31.3	143.7	1 426.3	59	(Straight) (Belpaire)	180	11 4	2	"	4 000	14 000	0 395
N. Y., L. E. & W.	6	4	0	"	"	"	68	20 x 24	113 000	100 000	30 000	76 000		186.	1 885	60	Wagon.	160	12 2	2	"	3 600		0.355
M. C.	6	4	0	"	"	Schenectady Compound.	74	20 and 29 x 24	135 000	99 000	36 000	(31 050 Empty)	28 2	141.2	1 839.5	58	"	180	13 0		"	3 800	16 000	0.389
Penn. R. R.	6	4	0	"	"	" " "	74	20 and 30 x 24	138 000	102 000	36 000	87 050	26.2	141.7	1 811.5	58	"	180	13 0	2	"	3 500	16 000	0 404
C. R. R. of N. J.	4	4	0	"	"	Vauclain Compound.	78	13 and 22 x 24	123 800	88 400	35 400		38 5			58	"	180	11 10	2	"	3 500		0.476
Penn. R. R.	6	4	0	"	"	" " "	72	14 and 24 x 24	133 000	104 000	33 000		28.3			62	Straight	180	14 0	2	"	3 600		0 542
Phila. & Reading	4	2	2	"	"	" " "	78	13 and 22 x 24	129 006	83 000	46 000		76	128.9	1 261.7		Wootten	170	10 0	1½	"			0.423
C., B. & Q.	6	2	0	"	"	C. B. & Q. Compound.	62	20 and 29 x 24	115 000	98 000	17 000		27.1	126.	1 380	66	"	160			"			0.417
C., M. & St. P.	6	4	0	"	"	Rhode Island Compound.	78	21 and 31 x 26	143 000	88 500	54 500	75 000				62	Wagon.	200	12 8⅝	2	"	4 000		0 554
W. N. Y. & Pa.	8	2	0	"	"	Single Expansion.	50½	19 x 26	126 870	110 650	16 220		29.				Straight	160	12 1½	2	Freight			0.424
B. & M.	10	0	0	"	"	"	50	22 x 28	150 300	150 300			37.5	180.	2 171	68	"	160	14 6	2½	"	3 480		0.453
C. C. C. & St. L.	6	4	0	"	"	"	56	19 x 24	128 200	99 600	28 600	76 800	18.2	147.	1 883.4	60	Wagon.	160	13 4½	2	"	3 700	14 000	0.301
B. & O.	8	2	0	"	"	"	50	21 x 26	125 000	113 400	11 600		28.7	155.	1 584	55	"	160	13 7	2¼	"			0 507
"	6	4	0	"	"	"	60	20 x 26	127 500	101 500	26 000		32.5	146.2	1 608	60	Straight	180	13 0	2¼	"			0.482
D. & I. R.	8	4	0	"	"	"	54	19 x 24	16 900	96 000	33 000	(31 000 Empty)	34 5	189.7	2 212.6	72	"	180	13 6	2¼	"	3 500	13 000	0.472
W. N. Y. & Pa.	8	2	0	"	"	Vauclain Compound.	50½	13 and 21 x 26	129 600	116 550	13 050		29.				"	175	12 11½	2	"			0.538
So. Pacific.	6	4	0	"	"	Schenectady Compound.	55	20 and 28 x 26	126 000	99 500	26 500		28.6	141.2	1 788.3	60	Wagon.	180	13 0	2¼	"	4 000	16 000	1.525
N. Y., L. E. & W.	10	2	0	"	"	Vauclain Compound.	50	16 and 27 x 28	193 000	170 000	23 000			182.5	2 208		Wootten	175	12 0	2¼	"	4 500		0.660
Cornwall & Lebanon.	8	2	0	"	"	" " "	50	14 and 24 x 28	150 000	135 000	15 000		37.3			72	Straight	180	13 6	2¼	"	3 600		0 675
C., M. & St. P.	4	4	0	"	"	" " "	62	12 and 20 x 26	122 400	87 970	34 430		18.2					175	13 7½	2¼	"			0.525
Illinois Central.	6	2	0	"	"	Rogers Compound.	56½	20 and 29 x 26	128 500	107 300	21 200		26.1				Belpaire.	180	11 0	2	"	3 500		0.512

Note.—The formula from which column marked "Ratio of cylinder power to weight available for adhesion," is calculated as follows:

$$\frac{2 \times \text{cylinder area} \times \text{boiler pressure} \times \text{stroke}}{\text{Weight on drivers} \times \text{diameter of driving wheel.}}$$

(Ratio of cylinder power of compound engines cannot be compared with that of the single expansion engines.)

Note.—Where the boiler pressure could not be determined from the description of the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be 160 lbs per square inch above the atmosphere.

For compound locomotives the figures in the last column of ratios are based on the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the cylinder power of single expansion and compound locomotives.

TABLE No. A2.

Giving Dimensions of Locomotives in Great Britain.

Name of Railroad Company.	Number of drivers.	Number of front truck wheels.	Number of rear truck wheels.	With or without separate tender.	Inside or outside cylinders.	Compound or single expansion.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Total weight on driving wheels. Pounds.	Total weight on trucks. Pounds.	Weight of tender, loaded. Pounds.	Area of grate. Square feet.	Firebox heating surface. Square feet.	Tube heating surface, square feet.	Diameter of shell of boiler. Inches.	Boiler, wagon top. Belpaire or straight.	Steam pressure per square inch. Atmospheric pressure. Pounds.	Length of Tubes. Feet and inches.		Diameter of Tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Coal capacity. Pounds.	Ratio of cylinder power to weight available for adhesion.
																			Feet.	Inches.					
Great Northern	2	2	2	With.....	Inside ...	Single Expansion...	91½	18½ x 26	91 056	38 976	52 080	86 240	18 4	508 7	1 001	50	Straight .	160	11	9	1¾	Passenger	.....	.....	0.627
London and North West	4	2	2	"	Outside ..	Webb Compound....	85	15 and 30 x 24	116 480	69 440	47 264	56 000	20.5	1216	1 346	51	" ..	175	10	1	2⅛	"	.....	.....	0 593
North London	4	4	0	"	Inside ...	Single Expansion...	71	17½ x 24	109 800	69 440	31 360	.....	16 62	91	1 050.7	50	" ..	160	.....	.....	1¾	"	1 320	2 800	0.374
" "	4	4	0	"	Outside ..	" ...	65	17 x 24	103 124	72 968	30 156	.....	16.62	91	800	50	" ..	180	10	⅞	1¾	"	1 020	2 800	0.413
Bristol and Exeter	2	4	4	Without..	Inside ...	" ...	96	18 x 24	94 408	35 840	57 568	67 200	24	153	1 598	54	.....	160	11	2	1¾	"	3 000	.....	0.323
Great Western	2	4	2	With.....	" ...	" ...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Midland	4	2	0	"	" ...	" ...	84	19 x 26	93 900	62 664	33 286	.....	17.5	110.16	1 011.46	51	Straight..	160	10	6	1¾	"	3 900	.....	0.448
"	2	4	2	"	" ...	" ...	90	19 x 26	96 320	39 200	57 120	.....	19.6	117	1 123.5	50	" ..	160	10	4	1¾	"	3 900	7 840	0.669
London and So. Western	4	4	0	"	Outside ..	" ...	79	18 x 24	101 720	67 648	37 072	78 400	17.7	110.18	1 051 13	52	" ..	160	10	8	1¾	"	2 800	7 840	0.366
Midland	4	4	0	"	Inside ...	" ...	84	18 x 26	.....	.....	.....	.....	.....	.....	.....	.....	.....	160	.....	.....	.....	"	.....	.....	.....
London B and So. C.	4	2	0	"	" ...	" ...	78	18½ x 26	88 700	63 456	28 250	61 150	21	114	1 386	63	" ..	150	10	2	1½	"	2 250	.....	0.412
London and N. W.	4	2	0	"	Outside ..	Webb Compound....	85	14 and 30 x 24	103 600	70 560	33 040	.....	20.5	150.1	1 242	.....	" ..	175	.....	.....	1⅞	"	.....	.....	0 495
" " "	2	4	2	"	" ...	" ...	72	12 and 24 x 24	84 200	.....	.....	47 800	15.13	120.2	911 7	.....	" ..	120	.....	.....	.....	"	1 440	170 cu. ft.	.....
Highland	4	4	0	"	" ...	Single Expansion...	68½	18 x 24	96 320	.....	.....	71 680	18.8	97.5	1 038.5	50	" ..	.....	10	4	1¾	"	2 250	.....	.....
North Eastern	4	0	4	Without..	Inside ...	" ...	60	16 x 22	.....	.....	.....	.....	.....	.....	.....	50.5	" ..	.....	10	9¼	2	"	9 0	.....	.....
Caledonian	2	4	2	With.....	" ...	" ...	84	18 x 26	93 856	38 080	55 776	75 040	.....	.....	.....	51	" .	150	10	7	1¾	"	2 850	.....	0.621
Great Western	2	2	2	"	" ...	" ...	92	18 x 26	.....	.....	.....	.....	19.23	130	1 120	51	" ..	150	10	11½	1⅝	"	.....	.....	.....
North British	4	4	0	"	" ...	" ...	84	18 x 26	91 400	.....	.....	71 680	21	119	983	52	" ..	.....	10	7⅜	1¾	"	2 550	11 200	.....
" "	4	4	0	"	" ...	Tandem Compound.	79	13 and 20 x 24	.....	.....	.....	.....	.....	.....	.....	.....	" ..	.....	.....	.....	.....	"	.....	.....	.....
Caledonian	4	4	0	"	" ...	Single Expansion...	78	19 x 26	109 940	68 209	32 760	78 100	19.5	122	1 047 2	52	" ..	160	10	1½	1¾	"	3 408	11 200	0.443
Glasgow and So. W.	4	4	0	"	" ...	" ...	73½	18¼ x 26	93 000	62 200	30 800	60 480	16	101	843	50	" ..	140	10	11½	1⅝	"	2 550	7 000	0.417
North Eastern	2	4	2	"	" ...	Worsdell Compound.	91½	20 and 28 x 24	104 550	39 760	64 790	89 703	20.7	121	1 016	51	" ..	175	10	11	1¾	"	3 940	8 960	0.713
" "	2	4	2	"	" ...	" ...	84	18 and 26 x 24	96 040	40 300	55 720	75 712	17 23	110	1 0.6	51	" ..	175	10	11½	1¾	"	3 138	8 960	0.547
South Eastern	4	4	0	"	" ...	Single Expansion...	84	19 x 26	92 960	62 944	30 016	68 320	16.78	105.5	917	52	" ..	150	10	⅞	1⅞	"	2 650	8 960	0.418
Waterford and Limerick	4	2	0	"	" ...	" ...	72	17 x 24	81 676	55 328	26 348	50 300	18	110	1 000	.....	" ..	150	.....	.....	.....	"	2 000	7 840	0.410
Great Eastern	2	4	2	"	Outside ..	" ...	90	18 x 24	105 760	43 600	62 160	.....	17.1	111	1 0.7	49	" ..	140	.....	.....	1¾	"	3 000	.....	0.436
London and N. W.	4	2	0	"	" ...	Webb Compound....	.....	11½ and 26 x 24	.....	.....	.....	.....	.....	.....	.....	.....	" ..	.....	.....	.....	.....	"	.....	.....	.....
North British	4	4	0	"	Inside ...	Single Expansion..	42	17 x 26	.....	.....	.....	.....	.....	.....	.....	52	" ..	150	10	8	1¾	"	950	.....	.....
" Eastern	4	0	4	Without.	" ...	" ..	60	16 x 22	.....	.....	.....	.....	.....	.....	.....	.....	" ..	.....	10	9¾	.....	"	960	.....	.....
L. C. and D.	4	0	4	" ..	" ...	" ..	63	17½ x 26	.....	.....	.....	.....	16.5	.....	.....	51	" ..	.....	11	3	1¾	"	963	.....	.....
London and N. W.	4	2	0	With.....	Outside ..	Webb Compound....	75	14 and 30 x 24	95 200	67 200	28 000	56 268	20.5	159.1	1 118.1	49	" ..	175	.....	.....	1⅞	"	2 160	11 200	0.584
Great Western	2	2	2	"	Inside ...	Single Expansion..	92½	20 x 24	98 560	42 560	56 000	.....	20.8	124	1 321	50.1	Wagon....	160	11	9¼	1¾	"	3 000	.....	0.613
" Northern	2	2	2	"	" ...	" ...	90	18½ x 26	91 056	38 976	52 080	90 244	18 4	109	936	50	Straight..	160	.....	.....	1¾	"	.....	.....	0.638
" "	4	2	0	"	" ...	" ...	78	17½ x 26	87 360	61 600	25 760	90 244	16.25	92.4	896.9	50.5	" ..	160	.....	.....	1¾	"	3 500	11 200	0 417
" "	2	4	2	"	Outside ..	" ...	96	18 x 28	101 136	38 080	63 056	90 244	17.75	109	936	50	" ..	160	.....	.....	1¾	"	3 500	11 200	0.624
Man., Shef. and Lincolnshire	4	4	0	"	Inside ...	" ...	81	18 x 26	103 040	71 792	31 248	78 400	18.85	99	1 179	51	" ..	160	11	⅛	1¾	"	3 080	.....	0.363
London, B and So. C.	2	2	2	"	" ...	" ...	78	17 x 24	74 800	30 250	44 550	.....	17	100	1 084	51	" ..	160	10	6	1½	"	2 250	4 4 0	0.738
London and N. W.	4	2	0	"	" ...	" ...	81	17 x 24	74 360	50 400	23 960	55 000	17.1	103.5	961	49	" ..	160	.....	.....	.....	"	.....	.....	0 427
Great Eastern	4	2	0	"	" ...	" ...	84	18 x 24	94 108	61 796	32 312	72 800	17.9	.....	.....	52	" ..	140	10	4	1⅝	"	2 640	4 500	0.329
London and Brighton	4	0	2	"	" ...	" ...	78	18 x —	.....	.....	.....	.....	.....	.....	.....	53	" ..	.....	9	10	.....	"	2 250	.....	.....
London and N. W.	4	2	0	"	Outside ..	Webb Compound ..	78	15 and 26 x 24	81 560	61 264	23 296	.....	17.1	103.5	980	49	" ..	175	10	1	1⅞	"	.....	.....	0 467
Midland	4	2	0	"	Inside ...	Single Expansion...	80	17 x 24	85 568	58 912	26 656	.....	17 5	110	1 115	49	" ..	160	10	11	1¾	"	2 000	.....	0.369
North London	6	0	0	"	Outside ..	" ...	62	17 x 24	98 392	98 392	0	.....	16.33	81	875.85	50	" ..	160	9	11½	1¾	Freight..	1 147	2 800	0.340
Cornwall Mineral	6	0	0	"	" ...	" ...	42	16½ x 20	67 880	67 880	0	.....	.....	70.7	752.8	.....	" ..	160	.....	.....	1¾	" ..	1 560	.....	0.450
So. Eastern	6	0	0	"	Inside ...	" ...	61	18 x 26	70 830	70 830	0	.....	.....	95.25	1 034	51	" ..	160	.....	.....	1¾	" ..	.....	.....	0.439
London and N. W.	6	0	0	"	" ...	" ...	60	17 x 24	64 168	63 168	0	.....	15	87 3	984	.....	" ..	160	.....	.....	1¾	" ..	.....	.....	0.460
Great Eastern	6	0	0	"	" ...	Worsdell Compound.	58	18 and 26 x 24	88 300	88 300	0	.....	17 9	105	1 103	52	" ..	175	10	4	1¾	" ..	.....	.....	0 435
Midland	6	0	0	"	Single Expansion...	62½	17½ x 26	84 952	84 952	0	.....	17.5	110	1 203	51	" ..	150	.....	.....	.....	1¾	" ..	.....	.....	0.353
L. B. and S. C.	6	0	0	"	" ...	" ...	47½	13 x 20	54 544	54 544	0	.....	10	55	470	.....	" ..	140	8	3¼	1¼	"	.....	.....	0 287
Great Eastern	6	2	0	"	Outside ..	" ...	54	19 x 26	104 384	85 344	19 040	62 832	17.8	102	1 291	54½	" ..	140	11	9½	1¾	" ..	2 600	.....	0.417
" "	6	0	0	"	" ...	" ...	58	17½ x 24	81 800	81 800	0	.....	17 9	105.5	1 055	52	" ..	140	10	4	1¾	" ..	3 080	11 200	0.341
Lancashire and Yorkshire	6	0	0	"	Inside ...	" ...	60⅝	18 x 26	94 416	94 416	0	.....	18.75	107.68	1 102.2	49	" ..	160	10	9¾	1¾	" ..	.....	.....	0 369
Tilbury and South End	4	4	2	Without..	Outside ..	" ...	73	17 x 24	126 336	71 820	54 516	.....	17	97	914	49	" ..	160	.....	.....	1⅜	" ..	1 300	4 480	0.332
Great Northern	6	0	0	With.....	Inside ...	" ...	60	17½ x 26	81 760	81 760	0	78 260	16.25	92 4	830	50½	" ..	160	.....	.....	.....	" ..	2 800	11 200	0.408
" "	4	0	2	"	" ...	" ...	66	17½ x 24	78 624	50 032	18 592	78 512	16.25	92 4	823 6	50½	" ..	160	.....	.....	1¾	" ..	2 800	11 200	0.407
London and N. W.	8	0	0	"	Outside ..	" ...	53½	19½ x 24	104 910	104 916	0	55 000	20.5	114.7	1 091.5	51	" ..	160	.....	.....	2⅛	" ..	.....	.....	0.409
Great Eastern	4	2	0	"	" ...	" ...	48	17½ x 24	80 300	31 700	58 600	.....	18	101	1 107	52	" ..	160	10	4	1	" ..	3 080	.....	0.358
Barry	6	0	2	Without..	Inside ...	" ...	51	18 x 26	126 560	.....	.....	.....	20.75	110	1 023	52	" ..	.....	.....	.....	2	" ..	1 750	3 584	.....
L. and S. W.	4	0	2	With.....	" ...	" ...	72	18 x 26	95 984	72 128	23 856	67 424	17	116.7	1 131.4	52	" ..	160	11	4	1¾	" ..	3 000	.....	0.407

NOTE.—The formula from which column marked "Ratio of cylinder power to weight available for adhesion" is calculated as follows:

$$\frac{2 \times \text{cylinder area} \times \text{boiler pressure} \times \text{stroke}}{\text{Weight on drivers} \times \text{diameter of driving wheels.}}$$

(Ratio of cylinder power of compound engines cannot be compared with that of the single expansion engines.)

NOTE.—Where the boiler pressure could not be determined from the description of the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be 160 lbs. per square inch above the atmosphere.

For compound locomotives the figures in the last column of ratios are based on the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the cylinder power of single expansion and compound locomotives.

TABLE A3.

Giving Dimensions of Locomotives in Other Countries.

Name of Railroad Company.	Number of driving wheels.	Number of front truck wheels.	Number of rear truck wheels.	With or without separate tender.	Inside or outside cylinders.	Single expansion or compound.	Diameter of driving wheels. Inches.	Size of cylinders. Inches.	Total weight of engine. Pounds.	Weight on driving wheels. Pounds.	Weight on truck wheels. Pounds.	Weight of tender, loaded. Pounds.	Area of grate. Square feet.	Firebox heating surface. Square feet.	Tube heating surface. Square feet.	Diameter of boiler. Inches.	Boiler, wagon top, Belpaire or straight.	Steam pressure. Pounds per square inch.	Length of tubes. Feet and inches. (Feet, Inches.)	Diameter of tubes. Inches.	Description of service for which engine is built.	Capacity of water tank. Gallons.	Capacity of coal tank. Pounds.	Ratio of cylinder power to weight available for adhesion.
	4	2	0	With	Inside	Single Expansion	78½	17 x 23.5	....	59 000	....	....	....	76	1 156	47	Straight	127	12 7	....	Passenger	....	....	0 292
Western R. R. of France	6	0	0	Without	"	"	60.6	16.9 x 23.6	83 000	83 000	....	....	11.7	81.8	989 2	48	"	142	10 6	1.77	"	850	2 500	0.304
" "	4	4	0	With	"	"	80 5	18 x 26	106 773	65 333	41 400	....	19	....	....	49	Wagon	156	13 8½	2	"	....	....	0 392
" "	4	2	0	"	"	"	81.5	17 x 24	....	68 000	....	....	25	98	1 211	49	Straight	140	13 5	....	"	....	....	0 318
" "	4	2	0	"	"	"	80 3	17 2 x 24	86 688	60 032	26 656	....	17.6	103.3	1 0-6.7	48.4	"	142	10 5	1 8	"	....	....	0 328
" "	4	2	2	"	"	"	79 5	17.6 x 26	96 544	60 480	36 064	....	17.6	95.7	1 107.5	48	"	170	16 3	1.8	"	....	....	0.447
French State	4	2	2	"	Outside	4-Cylinder Compound	78.7	19.7 and 12.2 x 24.4	117 947	....	....	....	26.2	....	....	19.7	"	213	....	....	"			
Paris, Lyons and Med	4	2	2	"	"	Single Expansion	83.5	19.5 x 25.5	....	60 000	....	....	22	96	1 417	....	"	140	....	....	"	346	8 800	0 430
" "	4	2	2	"	"	2-Cylinder Compound	78 7	12.4 and 20 x 24 8	118 840	66 304	51 536	....	25.2	124.7	1 059.9	49.6	"	213	13 3	1.8	"	....	....	0.307
" "	4	4	0	"	"	4-Cylinder Compound	77.6	13 4 and 21.2 x 24.4	107 620	67 200	40 320	....	25	....	....	....	Wagon	215	10 0	....	"	....	....	0.710
" "	4	2	2	"	Out and Inside	"	78 7	12.2 and 19 6 x 24.4	117 700	65 120	52 580	80 520	25.2	125	1 160.6	50.7	"	180	13 3	1.79	"	4 254	6 600	0.517
" "	4	2	2	"	Outside	Single Expansion	78.7	19 6 x 24 4	111 100	62 810	48 290	....	24.1	112 9	1 422.5	50.7	"	156.2	16 3	1.96	"	....	....	0 457
" "	4	2	2	"	"	"	80	17 x 25.5	....	56 320	....	....	16.3	112	1 632	....	Straight	127	....	....	"	....	....	0.311
Paris and Orleans	4	2	2	"	"	"	84.6	18 x 24	122 528	70 336	52 192	....	23.3	152 8	1 326.7	49.2	"	185	17 3	1.5	"	....	....	0 442
" "	4	2	2	"	Inside	"	78.7	17.7 x 27.5	120 340	69 080	51 260	74 030	23 1	152 6	1 326.6	49.2	Wagon	184.6	17 0	1 88	"	3 840	6 160	0 459
" "	6	2	0	"	Out and Inside	"	55	18.9 x 23.6	113 300	86 020	27 280	45 672	18 7	126 9	6 411.1	59	Straight	156.2	14 7	1.83	"	1 585	8 800	0 137
" "	4	2	0	"	Outside	"	68.5	15 x 22	67 000	46 050	20 950	....	9 47	51.67	726.7	....	"	....	....	....	"	517	1 100	
Northern R. R. of France	4	4	0	"	"	"	83 8	18.9 x 23 6	86 400	53 800	32 600	....	....	118 4	1 014.1	49.2	"	....	....	1.77	"			
" "	4	2	0	"	Inside	4-Cylinder Compound	84	18 4 and 13.2 x 24.4	81 672	61 724	22 918	....	21 4	102.2	1 006	48	"	156	11 8	1.8	"	....	....	0.390
" "	4	4	0	"	"	Single Expansion	83.8	19.4 x 24	96 768	60 256	36 512	....	21.9	148.5	1 043.7	49.2	"	170	12 6	1.8	"	....	....	0 477
" "	4	4	0	"	Outside	4-Cylinder Compound	83.2	13 4 and 20.9 x 25.6	105 350	67 220	38 130	71 050	21.9	146.7	1 051.8	49.8	"	190	12 8	1 77	"	3 900	8 800	0 534
" "	4	4	0	"	"	"	83	13.5 and 21 x 25	105 280	67 200	38 080	....	21 9	116.9	1 065 2	49.5	"	182	12 9	1.75	"	....	....	0 565
" "	4	1	0	"	"	"	83.2	13 4 and 20 9 x 25.2	105 380	67 210	38 140	....	22	117	1 094.5	49.6	"	199	12 9.5	1.77	"	....	....	0 614
" "	4	2	0	"	Out and Inside	"	82.6	18.1 and 13 x 24	74 404	....	....	....	24 4	....	....	52.2	"	156.4	....	....	"			
" "	4	2	0	"	Outside	Single Expansion	78 7	17 6 x 24	95 872	67 200	28 672	....	18.4	104.4	1 098 6	50.4	"	142	11 5	1.5	"	....	....	0.313
Southern R. R. "	4	4	0	"	"	"	82.2	19.7 x 26	122 950	72 150	50 800	....	26	170.7	1 768 5	31.5 & 47.5	Double barrel	....	14 11	1.5	"			
Eastern R. R. "	4	2	0	"	Inside	"	80.3	16.9 x 24.6	85 250	53 960	26 290	....	17.6	103 3	1 086.7	51.8	Straight	142	10 6	1.77	"	....	....	0 252
" "	4	4	0	"	"	"	80 3	18.1 x 25.9	105 160	64 460	40 700	....	19	107.6	1 913 3	52.4	"	156.2	13 8	1 92	"	....		0.402
" "	6	0	0	"	"	"	60 5	17 x 23.5	69 440	....	....	....	17	75	1 035	....	"	143	11 8	1.75	Freight	....	2 240	
Paris and St. Germain	8	0	0	"	Out and Inside	4 Cylinder Compound	59	21.3 and 13.4 x 25.6	125 414	....	....	....	25.6	....	....	55.1	"	213	....	....	"			
Paris, Lyons and Med	8	0	0	"	"	"	49.5	21.5 and 14 2 x 25.6	125 883	....	....	....	23 5	....	....	59	"	213	....	....	"			
" "	8	0	0	"	"	"	49.6	14 4 x 21 6	131 144	131 144	....	....	23.4	118.3	1 578.5	59	"	213	13 7	1 8	"	....	....	0 621
" "	8	0	0	"	"	"	49.6	14.1 and 21.2 x 25.6	126 620	125 620	....	67 682	23.5	117.9	1 578 7	60.3	Wagon	200	13 7	1.8	"	2 113	11 000	0.580
" "	8	0	0	"	"	"	59	13 5 and 21.2 x 25.5	125 180	125 180	....	....	25.5	112.6	1 489	56.2	Straight	213	14 2	1.77	"	....		0 519
" "	6	0	2	"	"	Single Expansion	59	21 2 x 25.5	115 829	94 928	20 900	....	23.8	112.3	1 549	56.2	Wagon	142	16 6	1.96	"	....		0 466
Paris and Orleans	6	2	0	"	Outside	"	60.6	19.4 x 24	115 584	87 584	28 000	....	18 7	126.9	1 751.7	59	Straight	156	14 9	1 5	"	....		417
Eastern R. R. of France	8	0	0	Without	"	"	61.4	18 1 x 23.6	122 595	122 595	....	....	19.6	95.7	1 092 4	51 1	"	142	13 5	1 92	"	1 157	5 619	226
" "	6	0	2	"	Inside	"	61.4	18 4 x 24	124 541	94 752	29 792	....	19 8	95.7	1 032.1	51.2	"	142	13 5	1.5	"	1 376 4	6 000	311
Northern R. R. "	6	2	0	With	Out and Inside	Compound	64.9	17 & 19 7 x 19 7 & 25.6	106 776	90 944	15 232	....	22.5	100.1	1 121 8	52.5	"	199	12 1	1.77	"	....	....	0 523
" "	6	2	0	"	"	3-Cylinder Compound	64.9	19.7 and 17 x 27.6	104 000	89 000	15 000	....	22.5	100.1	1 124.8	53	"	199	13 1	1.77	"	....	....	0.287
" "	8	0	0	"	Outside	4 Cylinder Compound	51.2	25.7 and 14 8 x 26 6	113 987	....	....	....	22.4	....	....	60	"	142	....	....	"			
" "	6	2	0	"	"	3-Cylinder Compound	64.9	17.7 & 20 x 20 & 28	106 176	90 944	15 232	....	22.6	100	1 121.4	52 9	"	199	13 1	1 8	"	....	....	0 296
" "	6	2	0	"	Out and Inside	"	64.9	17 & 19.6 x 19.6 & 27.5	104 280	89 320	14 960	....	22 5	100	1 121.4	55.1	"	198.8	11 1	1 77	"	....	....	0.289
Western R. R. "	6	0	0	Without	Inside	Single Expansion	60.6	17.2 x 24	92 960	92 960	....	....	13.7	81.8	988.8	48	"	142	11 4	1.8	"	1 058	1 443	0 281
French State	6	0	0	With	Outside	2-Cylinder Compound	59.4	17.8 and 24 x 24	76 384	76 384	....	....	14.5	81.7	1 000.6	49.2	"	128	11 1	1.8	"	....	....	0 204
Southern of France	8	0	0	"	"	Single Expansion	47.6	20 6 x 24 4	120 960	120 960	....	....	20 4	114	1 904.5	60.5	"	128	16 1	2.1	"	....	....	0 262
" "	8	0	0	"	"	Woolf Compound	51.2	15.4 and 26 4 x 26	116 480	116 480	....	....	22.4	99	1 278	59	"	142	13 5	2	"	....	....	0 677
Belgian State	4	2	2	"	Inside	Single Expansion	83	20 x 24	....	....	....	....	53.75	138	1 237	....	Belpaire	150	....	1.6	Passenger			
" "	6	2	0	"	"	"	67	19.5 x 24	....	....	....	....	....	....	....	56	Straight	....	13 2	....	"			
" "	6	2	2	Without	"	"	67	17.7 x 23.6	132 160	....	....	....	....	118	1 025	51	"	133	11 6½	1.77	"	2 200	3 920	
" "	4	2	0	With	"	"	70.8	18.11 x 24	94 080	....	....	....	36.6	129.2	1 053.8	....	"	142	....	....	"	....	....	0 309
" "	4	2	0	"	"	"	79	17 x 24	91 400	64 300	27 210	....	35	126	1 179	51	"	135	11 6	1.77	"			
" "	4	2	0	"	"	"	70.8	18 4 x 24 4	94 080	....	....	....	36.6	130.2	1 053.4	51.2	Wagon	150	11 6	1 8	"			
" "	6	2	0	"	"	"	67	19.7 x 23 6	117 000	90 100	26 900	....	61.8	161 4	1 412.5	55	Belpaire	150	13 3	1.97	"	....	....	0 357
" "	4	2	2	"	"	"	82.7	19 7 x 23.6	108 400	57 750	50 650	....	50.7	134.6	1 207 4	51 2	"	150	12 7	1.77	"	....	....	0 451
Prussian "	4	2	0	"	Outside	"	68.1	15.7 x 22	79 990	53 984	26 006	....	20.1	73.2	1 037.6	49.2	Straight	205.8	12 1	1.8	"	2 773	8 800	0 347
" "	4	4	0	"	"	"	77	16 9 x 23.6	110 000	....	....	79 000	10.76	....	....	....	Lentz stayless	142	....	1.8	"			
Belgian "	6	2	0	"	Inside	"	66.9	20 x 24	144 464	91 616	52 848	....	62.4	151.7	1 435.4	55 1	Straight	142	13 3	2	Freight	....	....	0 349
" "	6	0	0	"	"	"	51.2	20 x 24	100 800	100 800	....	....	55.4	121.6	1 177 1	55.1	"	142	11 6	1.8	"	....	....	0.416
" Central	8	0	0	Without	Outside	"	48	19.4 x 24	117 376	117 376	....	....	24.7	90.3	1 523.6	59	"	156	11 5	2	"	....	....	0 357
" State	6	0	0	"	"	"	47 2	14 x 20	68 768	68 768	....	....	22.2	73.1	497.1	43.3	"	150	8 4	1 8	"	....	....	0 296
" "	6	0	0	With	Inside	"	47.2	19 7 x 23 6	95 200	95 200	....	....	65 4	124	1 177	55.1	Belpaire	150	11 6	1.77	"	....	....	0 480
" "	6	0	0	"	Outside	"	52.3	17.7 x 24 8	84 700	84 700	....	62 700	16.4	77.4	1 269	55	Straight	174	14 3	2	"	....	....	0 413
Prussian State	8	0	0	"	"	Von Borries Compound	52 4	17.8 and 25.6 x 24.8	78 800	78 800	....	52 400	16.5	....	....	53	"	150	14 7	2	"	2 300	8 000	0 538
Med. R. R. of Italy	6	4	0	"	"	Single Expansion	66	18.5 x 21.5	....	....	....	57 000	24	114	1 600	60	Belpaire	....	15 0	2	Passenger	2 200	7 000	
So " "	4	4	0	"	"	"	75.6	17.9 x 23.6	87 000	56 000	31 000	49 800	....	....	....	51 2	Straight	150	11 9	1.97	"	4 938	8 000	
Italian Med	4	4	0	"	"	"	71.5	17 x 22	....	58 240	....	....	23	94	930	50	Wagon	150	11 6	2	"	875	....	0 330
" "	4	4	0	"	"	"	83	18 x 24.5	93 800	59 000	31 800	57 000	25	107 5	1 086 7	52	Straight	142	....	1.75	"	2 200	7 000	0 381
" Railway	4	4	0	"	"	"	75.6	14.2 x 24	94 080	58 240	35 840	....	21.5	88.2	988.9	52.3	"	142	11 9	2	"	....	....	0 245
" Med	4	4	0	"	"	"	75.6	18 x 24.8	111 656	66 080	45 676	....	24.7	107.6	1 086.7	51.6	"	150	12 5	2	"	....	....	0 378
Hungarian State	4	4	0	"	"	"	67.5	16.9 x 25.6	92 512	56 896	35 616	70 560	21.5	92.5	1 200	....	....	190	13 0	1.77	"	....	....	0 447
" "	4	4	0	"	"	Woolf Compound	78.8	14.5 and 21.7 x 25 6	....	....	....	....	....	....	....	....	Straight	....	....	....	"			
" "	4	4	0	"	"	4-Cylinder Compound	77	14.6 and 21 6 x 25 6	119 900	61 500	58 400	89 280	32	129.2	1 322.4	51.2	"	190	13 1	2	"	3 000	16 000	
" "	4	4	0	"	"	" "	72	14 1 and 21.6 x 25 6	108 800	55 800	53 000	81 000	32	140	1 452	51	"	....	13 1	2	"	4 488	8 000	0 887
Hanover "	4	2	0	"	"	Von Borries Compound	73.2	16.5 and 23 6 x 22.8	83 776	57 344	26 432	....	18 7	78.5	969.3	51	"	170	11 2½	2	"	....	....	0.405
St. Petersburg and Warsaw	4	4	0	"	"	2-Cylinder Compound	78	18.1 and 26.4 x 25.6	101 200	52 000	49 200	68 000	26.5	134.6	1 437.4	54.8	"	165	13 1	2	"	3 180	4 000	0.569
Jura Simplon	4	4	0	"	"	" "	72.1	17.7 and 26 4 x 25.6	105 950	63 600	42 350	66 750	26.4	97.4	1 286	52 3	"	170	12 5	1.75	"	3 640	9 000	0 518
Indian State	6	4	0	"	"	Single Expansion	51	18 x 26	102 816	78 064	24 752	60 704	22	114.3	1 119	....	"	160	....	....	"	2 500	12 180	0 531
" "	4	2	0	"	Inside	"	79	17.5 x 24	80 640	56 000	24 640	53 760	19.5	100.4	1 010 2	....	"	160	....	....	"	2 000	16 000	0 417
" "	4	4	0	"	Outside	"	66.5	17 x 24	82 208	53 760	28 448	62 328	17.1	87	989.5	....	"	160	....	....	"	2 000	16 000	0 487
" "	6	0	0	"	Inside	"	60	18 x 24	76 160	76 160	....	53 760	20	89.9	1 004	....	Wagon	160	....	....	"	1 500	16 000	0.427
" "	4	0	2	"	"	"	66	17 x 24	69 440	54 208	15 232	53 760	19.6	85.3	872.8	....	Straight	160	....	....	"	2 000	16 000	0.457
Great Indian Peninsular	4	0	2	Without	Outside	"	54	15 x 22	92 288	63 616	28 672	....	13	72	692	....	"	160	....	....	"	800	2 500	0 353
" " "	6	0	2	"	Inside	"	54	16 x 24	110 208	90 048	20 160	....	15	67	798	....	....	160	....	....	"	1 250	3 920	0.317
" " "	4	4	0	With	"	"	66	18 x 26	91 976	62 720	32 256	58 240	20	93.7	1 067	....	Straight	160	....	....	"	2 000	8 000	0.511
Bengal and Nagpur	6	4	0	"	Outside	Compound	51	18 and 26 x 26	109 880	75 320	34 560	74 520	22	104	1 119	....	"	160	....	....	"	2 500	22 000	0.575
" "	6	4	2	Without	....	Single Expansion	51	18 x 26	129 920	83 440	46 480	....	....	101	1 119	....	"	160	....	....	"	950	6 640	0.497
Oude and Rohilcunde	4	2	0	With	Outside	3-Cylinder Compound	72	12 and 24 x 24	72 500	51 500	21 000	48 000	15 4	101	911	....	"	160	....	....	"	1 800	16 000	0.418
Jura Berne Luzerne	6	2	0	"	"	Von Borries Compound	59	18½ and 25½ x 26	95 700	....	....	....	16	80.5	1 221.5	....	"	162	....	....	"	1 500	9 240	
" " "	6	2	0	"	"	" "	59 8	16.7 and 25.2 x 25.6	94 300	....	....	45 300	16.1	80.7	1 223.9	....	"	156	....	....	Freight	1 570	9 250	
Lanyo R. R.	4	2	2	Without	"	Single Expansion	52	14 x 22	78 400	....	....	....	12	70	654	....	"	....	....	....	"	1 000	3 600	
Italian Med	8	0	0	With	"	"	48	21 x 24	118 720	118 720	....	....	23	115	1 616	59	"	135	17 0	2	"	1 383	....	0 393
Indian Midland	6	2	0	"	Inside	"	54.5	17.5 x 24	107 688	91 728	15 960	....	19	85	949	49	"	160	10 10	2	"	800	6 000	0 369
Swedish State	6	4	0	"	Outside	"	51	18 x 26	....	....	....	....	22	108	1 119	52	"	165	11 5	1¼	"			
" Norwegian	8	0	0	"	"	"	51	20 x 26	....	....	....	....	....	115	1 295	54	"	....	11 7	2	"	1 800		
Belgian State	6	0	0	"	Inside	"	51	19.6 x 23.5	96 320	96 320	....	....	65	121	1 170	55	"	150	11 5¼	1¼	"	....	....	0.434
St. Gothard	8	0	0	"	Outside	"	46	20.5 x 24	114 000	114 000	....	....	23	102	1 600	60.4	"	....	13 9	1.97	"			
Swiss No. Eastern	4	0	0	Without	"	"	54 7	12 6 x 23.6	....	....	....	....	11.9	55.5	688 4	....	"	....	9 10	1.97	"	708		
Japan Ry	6	2	0	With	"	"	48	18 x 22	80 000	72 000	8 000	....	....	....	....	37	"	150	10 9	2	"	2 640	....	0 485
New So. Wales	6	2	0	"	"	"	60.5	18 x 26	98 000	79 000	17 000	72 700	17	123	1 066	55	"	150	10 10¼	2	"	3 600	10 000	0 415
" "	8	2	0	"	"	Von Borries Compound	51	13.5 and 32 x 26	137 000	123 000	14 000	72 000	21.4	138	1 503	64	"	160	13 4	2¾	"	3 400	....	[illegible]
Japan Ry	4	2	2	Without	"	Single Expansion	52	14 x 20	....	....	....	....	12	70	654	....	"	....	....	....	"	1 000	3 400	
St. Gothard	12	0	0	"	"	Mallett Compound	48	15.5 and 22.5 x 25	188 160	188 160	....	....	23	102.2	1 597.8	....	"	150	....	....	"	1 800	8 200	0 330
Argentine No. Eastern	6	0	0	With	"	Single Expansion	48	14 2 x 23.3	66 752	66 752	....	....	13 5	63.4	697.2	43.9	"	139	10 6	1.8	"	....	....	0 320
Saxon State	8	0	0	Without	"	4-Cylinder Compound	43 2	11.8 and 18 1 x 21	112 400	112 400	....	....	11.7	58.2	871.8	....	"	170	....	....	"	1 200	4 000	0 377
Russian R. R.	8	0	0	"	"	Single Expansion	47.3	19 7 x 25 6	124 746	124 743	....	....	19.9	98.5	1 350.3	57.9	"	150	12 2	....	"	....	....	0.396
Uruguay Cent	4	4	0	"	"	2-Cylinder Compound	60	16 and 23 x 22	....	....	....	....	16	87	743	....	"	....	....	....	"	2 000	8 500	
" "	6	2	0	With	"	" "	54	17½ and 25 x 24	....	....	....	....	17.5	86	940	....	"	....	....	....	"	1 700	8 500	
St. Gothard R. R.	12	0	0	Without	"	Mallett Compound	48.5	16.7 and 32 8 x 25 2	170 000	170 000	....	....	....	....	....	....	"	180	....	....	"	....	....	0 929
Indian State	8	0	0	"	Inside	Single Expansion	48	18 x 26	134 400	134 400	....	....	22	....	1 150.5	....	"	160	....	....	"	1 550	7 200	0.328
" "	6	0	2	"	Outside	4-Cylinder Compound	....	15 & 18.9x23.6 & 15.7	113 740	86 970	26 770	....	....	....	....	....	"	160	....	....	"			
" "	6	0	0	With	"	Single Expansion	50	19 x 26	97 328	97 328	....	87 136	22	101	1 278.5	....	"	160	....	....	"	3 000	....	0 484
Oude and Rohilcunde	8	0	0	"	Inside	"	48	16.5 x 24	66 000	66 000	....	56 000	16.5	101	1 007	....	"	150	....	....	"	1 700	16 4 0	0 185
Mexican Ry	12	0	0	Without	Outside	"	42	16 x 22	184 000	184 000	....	....	33	180	1 532	....	"	165	....	....	"	2 850	....	0 188
" Central	12	2	2	"	"	Johnstone Compound	48	13 and 28 x 24	230 000	200 000	30 000	....	....	....	....	52	....	180	15 9	2 75	"	3 000	10 000	0.357
Royal Saxon	8	0	0	"	"	M. L. D. Compound	43.3	12 and 18 x 21	104 400	100 400	....	....	15	59	871	....	Straight	184 7	....	....	"	1 300	6 960	0 227
Saxon State	8	0	0	"	"	Meyer Compound	44	12 and 18.4 x 21.3	114 240	114 240	....	....	14.7	59.2	870.7	....	"	170.6	....	....	"	1 325	4 256	0.886

Note. Where the boiler pressure could not be determined from the description of the locomotives, as given by the builders and operators of the locomotives, it has been assumed to be 160 lbs. per square inch above the atmosphere.
For compound locomotives the figures in the last column of ratios are based on the capacity of the low-pressure cylinders only, the volume of the high-pressure being omitted. This has been done for the purpose of comparison, and because there is no accurate simple way of comparing the cylinder power of single expansion and compound locomotives.

incongruous the designs may appear in some cases, as a result of the use of the same parts for large and small engines, yet railroad men prefer that the harmony of design should suffer rather than keep in stock a larger supply of duplicate parts.

In Conclusion.—The important distinctive features of American locomotive practice are large dimensions, great hauling power, duplication of parts, steel fireboxes, bar-frames, the universal use of equalizers for all types, and cast-iron driving-wheel centers ; these are manifest advantages from an American standpoint; also, as distinctive features and of questionable advantage, are tenders with swiveling trucks, and small drivers for high speeds. A distinctive feature and a decided disadvantage is the use of heavy reciprocating parts.

The locomotives used in foreign countries are now, generally speaking, of about the same weight and power as those used here 10 years ago, and the heaviest foreign types for passenger service are about the same weight as our light eight-wheel type. There are none used elsewhere on comparatively level roads that are as powerful as our ten-wheel and mogul express engines. The average practice in various countries is given in Tables A1, A2, A3, which shows how closely some of the foreign types approach the American in general features of construction. Abroad there are many and varied types of locomotives, and abrupt changes in construction are more common than in the United States. So varied are the plans followed, and so rapidly do the changes in important details take place, that the onlooker receives the impression that a general dissatisfaction exists. Recent developments have followed American plans, both in weight and type, in a way that is complimentary, and there is some evidence that when foreign locomotive designs become more constant, and the process of selection evolves a nearly universal set of types, some of the features that are now distinctively American will find a place in the ultimate plan. One distinctive feature of the American locomotive construction that will eventually become universal is the steel firebox. The policy of hauling heavy trains, which is a distinctive feature of American locomotive practice, is so clearly advantageous that sooner or later all countries having long distances and competition between common carriers will run heavy trains and will construct ponderous locomotives to haul them.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

618.

(Vol. XXIX.—August, 1893.)

COMPARISON OF MODERN ENGINE LOADING, WITH STANDARD SPECIFICATIONS FOR SPANS FROM 10 TO 200 FEET.

By C. D. PURDON, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The World's Columbian Exposition having called attention to a number of engines of the latest designs and of much greater weight than have been used heretofore, the writer has thought it interesting to compare these engines, with regard to the effect on a bridge, with the engines specified as typical by some important roads.

One diagram (Plate I), from certain bridge specifications, shows a series of curves representing the loading from the typical engines specified. This diagram is made by calculating the bending moment

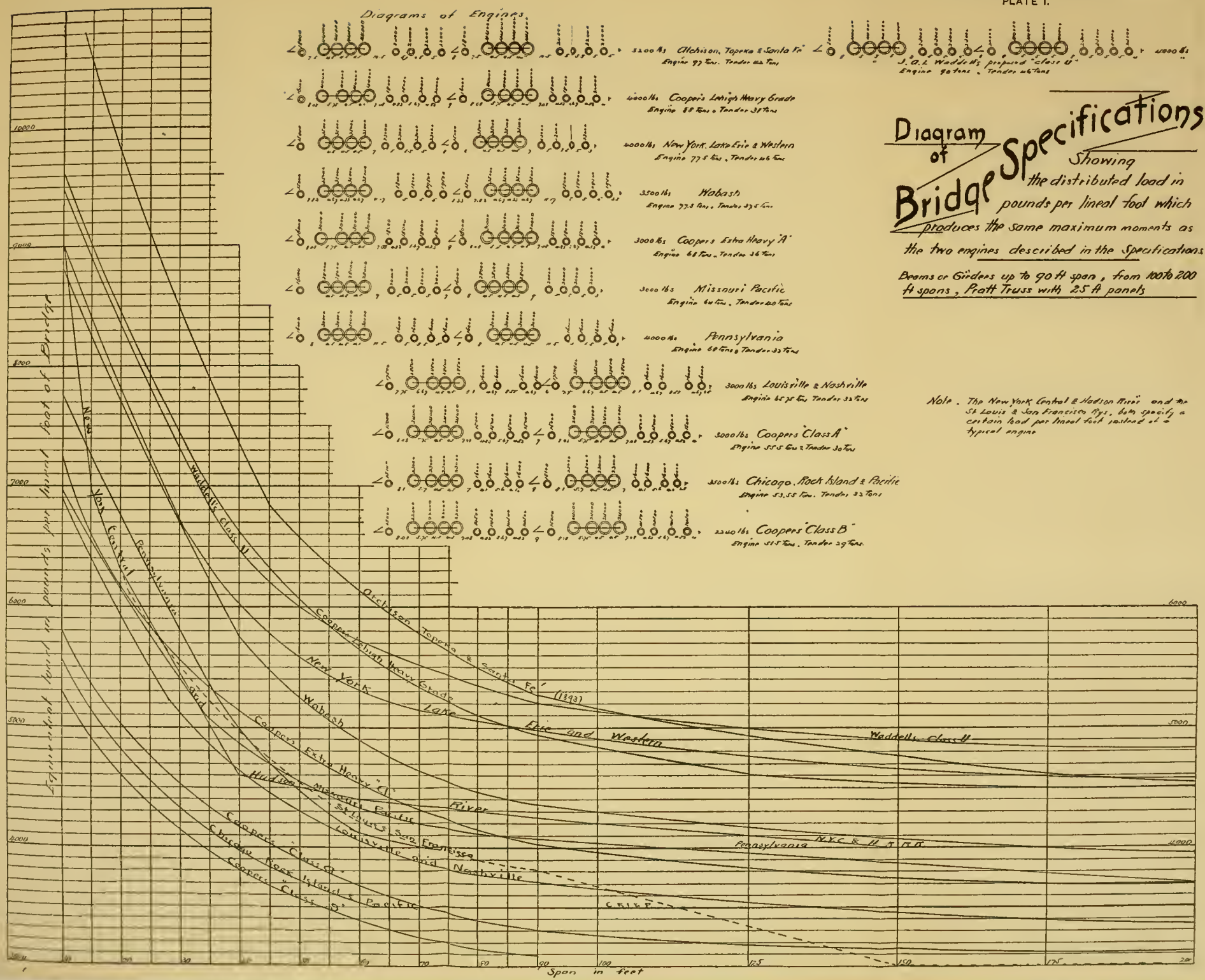
NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Diagram of Bridge Specifications

Showing the distributed load in pounds per lineal foot which produces the same maximum moments as the two engines described in the Specifications

Beams or Girders up to 90 ft span, from 100 to 200 ft spans, Pratt Truss with 25 ft panels

Note. The New York Central & Hudson River and the St Louis & San Francisco Rys. both specify a certain load per lineal foot instead of a typical engine



NOTE.-

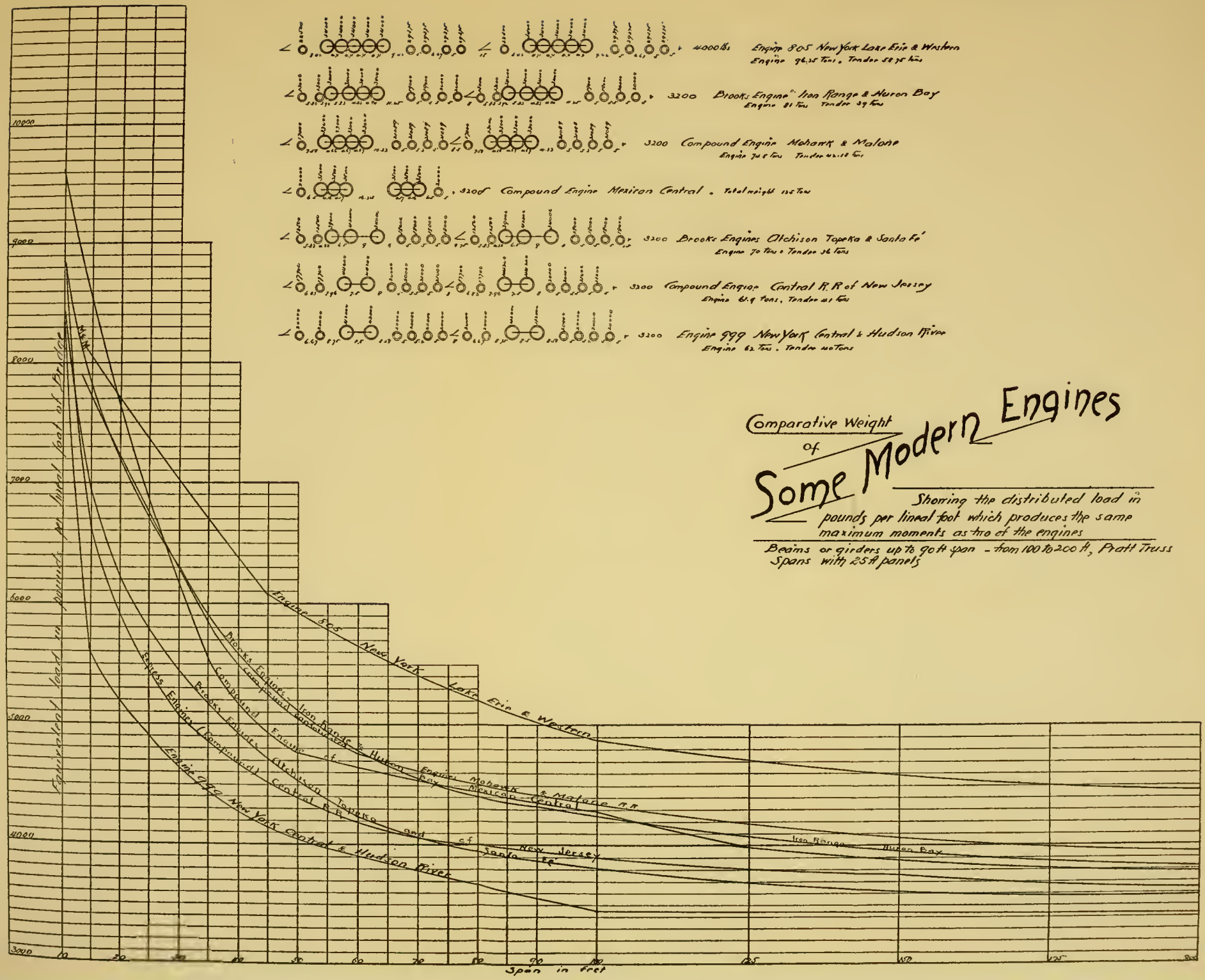
COI

P

nun
tha
to (
the

seri
spe

will


400000 lbs Engine 805 New York Lake Erie & Western
Engine 96.25 Tons. Tender 58.75 Tons
3200 Brooks Engine Iron Range & Huron Bay
Engine 81 Tons Tender 39 Tons
3200 Compound Engine Mohawk & Malone
Engine 74.5 Tons Tender 42.18 Tons
3200 Compound Engine Mexican Central. Total weight 115 Tons
3200 Brooks Engines Atchison Topeka & Santa Fe
Engine 70 Tons. Tender 36 Tons
3200 Compound Engine Central R.R of New Jersey
Engine 61.9 Tons. Tender 41 Tons
3200 Engine 999 New York Central & Hudson River
Engine 62 Tons. Tender 40 Tons
Comparative Weight of Some Modern Engines
Showing the distributed load in pounds per lineal foot which produces the same maximum moments as two of the engines
Beams or girders up to 90 ft span - from 100 to 200 ft, Pratt Truss Spans with 25 ft panels
Engine 805 New York Lake Erie & Western
Brooks Engines Iron Range & Huron Bay
Compound Engine Mexican Central
Express Engines (Compound) Atchison Topeka and Santa Fe
Express Engines (Compound) Central R.R. of New Jersey
Engine 999 New York Central & Hudson River
Engine Mohawk & Malone R.R.
Iron Range Huron Bay
Pounds per lineal foot of distributed load
Span in feet

of the engines on girders up to 90-ft. spans, beginning at 10-ft. spans and increasing by 5 ft.; and on Pratt trusses from 100-ft. to 200-ft. spans, beginning at 100 ft. and increasing by 25 ft., using panels 25 ft. long. After calculating the bending moment, the writer then found the distributed load per linear foot on the same spans, which would cause the same moments. Then plotting these loads on the diagram, he drew a curve to pass as nearly through all the points as possible. From spacing of the wheels, etc., a line representing the actual moments would be somewhat irregular; the curve gives a fair average.

The other diagram (Plate II), from some modern engines, was made precisely in the same way. The information at hand did not always give quite enough data for an accurate diagram. The distance between two engines and the distance from the last wheel to the head of the train not being given, these were assumed, as was also the following—load of 3 200 pounds per linear foot, except in the case of engine No. 805, New York, Lake Erie and Western, when 4 000 lbs. were taken. Although it is not probable that two engines like No. 805 would be coupled together in actual service, still, as nearly all bridge specifications use two engines, it is better for the purposes of comparing actual with typical engines to consider them in the same way.

It will hardly be necessary to say to engineers that, although the diagrams show a comparison between actual and theoretic loads, they do not show as fairly a comparison between the actual strains in a bridge in carrying these loads, as there is quite a difference in the unit strains on iron or steel used by the different specifications, probably fully as much as 20 per cent.

The diagrams do not by any means show all the engines at the Exposition, but show that the tendency is still towards heavier loads on track and bridges.

In two specifications, the Pennsylvania and the Rock Island, the effect of the two typical engines, followed by the train-load, would, in the case of the longer spans, fall below the effect of the train-load alone. In these cases the moments from the engines were calculated until the equivalent load equaled the train-load, and then the curves were continued along a horizontal line equal to the train load.

Two roads, the New York Central and the St. Louis and San Francisco, do not specify any typical engine, but use a certain load per linear foot of bridge, varying with the length of span.

The following unit strains are specified to be used in tension by the several roads named:

Railroad.	Plates and Shapes.	Bars.
A. T. & S. F.	$7\,500 \times 1 + \frac{\text{min.}}{2 \text{ max.}}$	$9\,000 \times 1 + \frac{\text{min.}}{2 \text{ max.}}$
Cooper	7 500 live, 15,000 dead	8 000 live, 16 000 dead.
N. Y., L. E. & W.	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$
Wabash	8 000	9 000 to 10 000, according to size of bar.
Mo. Pac	8 000	8 000 live, 16 000 dead.
Penna.	$7\,000 \times 1 + \frac{\text{min.}}{\text{max.}}$	$7\,500 \times 1 + \frac{\text{min.}}{\text{max.}}$
L. & N.	8 000 Under 20; 25%, decreasing to 5%	9 000. Impact added on spans.
C. R. I. & P.	7 000	8 000.
Frisco.	8 000	10 000.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

619.

(Vol. XXIX.—August, 1893.)

SURVEYS FOR RAILWAY LOCATION.

By F. A. GELBCKE, Engineer of Government Railways at Cologne, Prussia.

Translated from the German by R. P. MILLER, Jun. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Introductory.—Railroads, the offspring of the 19th century, have developed in a few decades with remarkable rapidity, both in the old and in the new world and have left an indelible impress on our planet. With a length of 620 000 km. (in round numbers) or more than 15 times the length of the equator, they now cover the civilized countries of the earth and still continue to branch out. Here, they press boldly into large territories not yet open to commerce; there, they weave smaller meshes into the already existing network of rails; everywhere they distribute rich blessings to the inhabitants, and hence, too, are everywhere desired. The growth of railroads is incessant and will continue, taking the whole world into consideration, for many centuries.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The art of projecting and building railroads develops continually; the most difficult problems do not frighten us off. The natural development of railroading is that roads should enter into lands increasing with difficulties, after the simple projects, those more easily handled, have been carried out. The disposition of the immense sums spent and yet to be spent for the construction of roads is placed in the hands of engineers, who devise the plans for the roads and construct them, trusting to their scientific knowledge and their integrity of character. Hence arises the duty of the engineers to seek with untiring energy for methods by which the entrusted capital may be husbanded to the best advantage, and to invent means by which can be accomplished the greatest results with the least money.

Among the effective means at the disposal of the engineer for reducing the cost of construction must be counted the thorough study of the survey. Defective surveys, in most cases, result in an impracticable and expensive location, while thorough and systematically conducted surveys always furnish a practicable and cheapest possible location.

The following discussion purposes to describe the manner in which the engineer should conduct his surveys, in order to accomplish his object, the most practicable location. Far from any intention of discussing all the details of railway surveys, it is purposed in a few words to treat only a practicable system of executing railway surveys, and to show, on the other hand, how often surveys are still impracticably conducted. This subject seemed to the writer, in view of the great financial consequences involved, to be of sufficient importance to be presented at the International Engineering Congress.

Railway surveys are divided into general and detailed (preliminary and location). The general surveys are, it is true, preceded by general investigations (reconnaissance), and the detailed surveys (location) are followed by preparations for the construction of the road. A clear distinction of these different technical operations will prove of benefit to the thorough study of railway projects. It is therefore proposed to divide railway surveys into the following four divisions:

1. General Investigations (reconnaissance).
2. General Survey (preliminary).
3. Detailed Survey (paper location).
4. Field Location and Preparation of Expropriation Plans.

1. *The General Investigations* (*reconnaissance*).—These constitute the first problem which confronts the engineer when the construction of a railroad is proposed. Whether it be the Government, a corporation, or private individuals who desire the construction of a railroad, it must be determined whether the proposed road, as yet without definite location, will be practicable and self-sustaining, and what its estimated cost will be. In the older civilized countries useful topographical maps may be found, on a scale of 1 to 100 000, or perhaps even on a larger scale. In other countries there are probably few such maps, and the engineer is compelled to obtain a general view of the territory in question in a different manner. If a map with topographical details is to be had, it must still, in most cases, be supplemented for the purpose of the reconnaissance. The water-courses must be indicated more plainly by blue lines. The whole territory must be traversed and the comparative elevations, which are of foremost importance, must be indicated on the map. And here it may be remarked that for such preliminary level investigations barometrical measurements are especially well adapted, but, as a matter of course, they must be based on a chain of well-determined heights, which latter may, however, be widely separated. If no map is to be had, the engineer must, with the simplest possible means, make such an one. All sorts of measurements become necessary for this, and they naturally increase the expense of the reconnaissance to some extent. Finally, if the general line is to be fixed by the reconnaissance, a map of the territory in question, showing elevations, cannot be spared under any circumstances.

This map, however, will also serve other purposes. Besides the study of the practical difficulties to be met, the populations of the various cities and villages, at what points large industrial establishments, mines, forests, etc., are located, must be determined. These facts must also be indicated on the map. The population is well represented by drawing, at the points in question, circles whose areas are proportionate to the population. These circles are made more distinct by being tinted with some light color. They will then indicate almost at a glance which line is most thickly populated and which, in this respect, would offer the most practicable route for the railroad.

With such a map as just described, it will be an easy matter for the experienced engineer, considering the general, concurrently determined, condition of the territory, to make practical suggestions for the

selection of this or that route, perhaps to propose for further investigation several alternate lines; in general, to explain how the line of the road will appear, what stations it will have, how it will be operated and about how much the construction and operation of the road will cost. When a satisfactory decision has been reached, then the general investigations or reconnaissance are completed. It should here be emphasized again, that, for a really satisfactory conclusion, the preparation and use of a map in which topography, population and industries of the territory are shown, is almost indispensable. The engineer should guard against expressing judgment on the location of the road without such a carefully prepared map, thus relying on the impressions of his travels. The latter often lead on an entirely wrong track from which it is subsequently difficult to part. It is further important to include a great width of the territory to be examined and represented on the map, so that under all circumstances it will include every possible solution for the location of the road. The expenses of such general investigations are small, but on the other hand their value is very great if they are thoroughly and completely executed. They then give the assurance that nothing has been overlooked, and that routes have been proposed for construction which court further investigation and are plainly the most practicable.

In a few more words it may be stated that for the study of local difficulties it may become necessary, even in the general investigations, to represent portions of the territory on a larger scale than that used in the general map, for instance, 1 to 20 000, or 1 to 10 000. Beyond that it will seldom be necessary to go.

As far as the expenses of such general investigations are concerned, they depend on the available maps and the general characteristics of the territory to be examined. It may be asserted, however, that the engineer can undertake and complete the general investigations for the route of a railroad for 20 to 40 marks per kilometer.

2. *General Survey.*—The preliminary survey must be based on the general investigations described above, and is intended to advance the project and to decide which of the alternate lines is to be preferred. The preliminary survey furthermore serves to determine the cost of construction and operation of the road with such sufficient exactness that the capital can be furnished or subscribed, and that an excess of the cost of construction, as determined by the reconnaissance, may be excluded.

In the map of the reconnaissance the several alternate lines to be considered are shown. These must now be more closely studied and compared, and the most practicable one must finally be chosen.

In the preliminary survey are also to be investigated the nature and characteristics of very large stretches of country, measuring mostly several hundred square kilometers. The general map, on a scale of 1 to 100 000, as we have described it, is no longer sufficient, but it becomes absolutely requisite to plot the surveys on a larger scale, so that it is possible to study the course of the road more exactly, and to undertake a reliable calculation of the difficulties to be met and their cost. There are also to be obtained in the preliminary survey, above all, the measurements for, and preparation of, a map of positions and elevations which shall contain all the necessary information for the study of the project. During a long practice the writer has found that such a map is made to the best advantage on a scale of 1 to 2 500, and, under very simple circumstances, of 1 to 5 000; and that it is further of advantage for the review of the whole project to construct from these plots another general map on a scale of 1 to 10 000, indicating the road on it by a single line, and to draw along its side a profile on a scale of 1 to 500 for the heights.

Assisted by the general map (of the reconnaissance) it becomes easy to pick out the stretches of country which come into question in the preliminary survey, and of which it next becomes necessary to make plats on a scale of 1 to 2 500. In this connection care must be taken that the limits of these stretches are not taken too narrow. Thus, a greater extent of measurements and the corresponding plats become necessary in the case of flat country or of water-sheds than in the case of narrow valleys, in which only a narrow strip of land can enter into the question of the location. It is recommended in the case of narrow valleys always to consider both slopes of the valley in the extent of the survey.

Since then, in the preliminary survey, we deal with the measurement of extended areas, and since, on the other hand, a precise determination of heights, even with reference to the scale of the plats, is not at all requisite, the barometer is here exceedingly well adapted for the determination of levels. In the hands of an experienced engineer it is an instrument of extraordinary efficiency and sufficient accuracy. The engineer himself, furnished with a barometer, must mount all heights

to be determined, and in this way he also acquires a comprehensive knowledge of the country, quite invaluable in the study of the general project. Other methods which can be applied in preliminary surveys may be mentioned; as, for example, plane table surveys, or notes by means of the tachymeter; or, finally, and to be least recommended, cross-section measurements. But none of these methods are so well adapted for preliminary surveys as barometrical measurements. The writer would here describe, in a few words, an approved, though unfamiliar, procedure of the barometrical determination of heights, for the purpose of preliminary surveys.

The equipment of a corps of about five engineers for undertaking barometric measurements for the purposes of the preliminary surveys is, considering the rapidity of progress, comparatively simple, and consists of four levels and level rods, three sextants, two plummets, two tape measures, twenty ranging poles, five leather bags, about eight aneroid barometers, one or two barographs, and three sling thermometers for the determination of atmospheric temperature; lastly, every engineer must be provided with a good pocket timepiece. Every engineer should have but one assistant, whose duty is chiefly to carry instruments and keep field notes.

The determination of heights by means of the aneroids, to be reliable, must rest on a network of elevations which have been determined by the spirit levels at such distances that at intervals of from half to one hour the readings of the aneroids can be taken at such points. For the determination of changes of atmospheric pressure during the work the barographs are used, that is, aneroid barometers, which automatically register the pressure on a strip of paper moved by clockwork. The barographs may be dispensed with if the determined heights are taken so close that every engineer in the field can read his aneroid at one of these fixed points, not less often than every half hour. Under these circumstances it may be generally assumed that the pressures change regularly in the meantime. In the determination of heights for engineering purposes, the aneroids of Naudet, of Paris, Bohne, of Berlin, and Hottinger, of Zürich, and especially those of the last-named manufacture, have proved most satisfactory. The work is much simplified if the aneroid is independent of temperature, a condition which Bohne, of Berlin, has almost accomplished by means of a compensating attachment. But all aneroids which have thus far been

in use change their readings with time, and it is, therefore, absolutely necessary to subject all the instruments, before every campaign (*i.e.*, once a year), to an examination and to make new correction tables for them.

The measuring of heights with the aneroid always presupposes the existence of a map of the territory in question, or that the positions of the stations, whose elevation is desired, are easily determined. If there are maps, as, for instance, maps that show the ownership of property, they are to be used drawn to a scale (say, 1 to 2 500, or 1 to 5 000), and for further use they may be manifolded to great advantage by some printing process. It has proven disadvantageous to make the separate sheets more than 1.2 m. long and 0.60 m. wide. If no maps are to be had, nothing remains for the engineers but to lay out a network of lines over the whole of the land to be measured; to put on paper this network, which also should contain the elevation stations, on a scale of 1 to 2 500 or 1 to 5 000, and to fill in the meshes of this network by the use of the pedometer at the time of making the aneroid measurements. In either case, where there is or is not a local map, the determination of elevations by aneroids must be preceded by a line of levels obtained by spirit levels, which needs, however, follow only approximately the prospective route without strained exactness, but which, for the sake of certainty, must be made by two engineers, independently, and the purpose of which is to establish bench marks at distances of about 200 or 300 m. For the elevations of the leveling of n kilometer distances, an approximation of $80\sqrt{n}$ millimeters will be sufficient.

On account of the great width of the territory to be surveyed (about 1.5 km.), the principal line of level must furthermore be supplemented by various secondary lines of leveling, which are to be connected with the principal line at various points, and must contain most of the easily accessible bench marks. Great accuracy is not required in the secondary lines. In a distance of 2 km. an error of 20 cm. may still be admitted. The elevation stations of the secondary lines are also to be distinctly entered on the field map.

We can now proceed to the barometric leveling. Barometers are intended for the measurement of atmospheric pressure, which is dependent, not only on the elevation of the point of observation, but also on various other circumstances, and is also variable in time.

Now, if observations of the atmospheric pressures are simultaneously made at two points which are not separated very far in space (the best practice is not to exceed 15 km.), the difference of the observed pressures will correspond to the weight of the column of air which lies between the two horizontal planes passing through those points. The height of this air column equals the required difference of elevation between the two points. It can be calculated, according to a formula based on experience (the so-called barometric formula), if the pressure at each point of observation is known, besides the mean temperature of the air column.

If a barograph is used in connection with these observations, it is so set up that it is about at the center of the field to be measured, and that the engineers with the aneroids do not get farther away than 15 km. at the most; otherwise the position of the barograph must be changed.

In carrying out the measurements, the engineer begins with some determined bench mark of the local map, looks for that point in the field, and at the same observes the time, the aneroid temperature, and the reading of the aneroid, after having lightly tapped the same, to cause the instrument to work freely. The field map or plan is fastened to the portfolio that the assistant carries. The assistant also has a timepiece hung from his neck. Lead-pencil and pedometer are tied to the coat of the engineer, that he may have his hands free for the measurements.

Having started from well-determined stations, the intermediate stations of the territory can be located by pacing and comparison with the distances on the field map, and recorded, in the case of a simple configuration of the ground, for every 50 double paces (100 yards); but in the case of more complex configuration more frequent points are required, by pacing the border lines or simple construction lines, and the heights must be determined barometrically.

The line to be followed by the observer is previously determined by the condition that inside of a half or one hour at most, the reading of the aneroid must again be taken at some bench mark, that is, some station of well-determined elevation. The extent of the territory to be measured in the meantime depends on the skill of the observer, the clearness from obstructions, the worth of the aneroid and the configuration of the ground. After a little experience, the engineer can easily tell at a glance which line to follow.

For the certain determination of heights, it is also important to take so-called check stations, that is, to repeat barometric observations at some point after a lapse of time (for instance, after one or two hours), thereby obtaining a check on the change of pressure and on the correctness of the readings of the aneroid.

One engineer of average experience, with an assistant, can locate and determine the elevation of 100 stations in a hilly district in one day. Very experienced observers can accomplish double that amount. The stations lie on an average of 50 to 60 double paces apart (100 to 120 yds.).

For the determination of atmospheric temperature, the sling thermometer, already mentioned, is used, by swinging the same on a string in the atmosphere, in a shady spot, until it indicates a stationary temperature. According to the season and the geographical location of the place it becomes necessary to make these temperature observations two or three times a day.

The calculation of the heights of the barometrical observations is done most satisfactorily by graphical means. The aneroid readings, corrected for temperature, are plotted on cross-section paper. On these, with the aid of the notations of the barograph and the readings at the bench marks and check stations, a horizontal curve is constructed. Thus, an aneroid diagram is formed, from which it is only necessary to read the ordinates of the curve at the stations on the diagram, with a scale varying to suit the observed changes of temperature of the day, in order to obtain the elevation of the stations. This graphical diagram was invented by Engineer Steinach, and described in detail by the inventor, in 1881, in the first number of *Zeitschrift des Architekten und Ingenieur-Vereins zu Hannover*. It furnishes the desired results quickly and without any calculation, so that large errors in the determination of elevations are completely excluded. Concerning the accuracy of the aneroid measurements—for instance, those of aneroids of Hottinger—variations of pressure corresponding to 0.01 mm. of quicksilver, or about 0.1 m. of elevation, can be read, although it is not possible to carry out such accuracy in the field. Experience has shown, however, that a careful observer is able to reach an approximation of 1 or 2 m. elevation with certainty, which, on the scale of 1 to 2 500, 1 to 5 000, or even 1 to 10 000, chosen for the plat, is sufficiently close. The view often advanced, that the

aneroid does not offer sufficient accuracy for preliminary surveys, is unfounded.

After the heights have been determined, the entering of the elevations and contours in the plat, and the completion of the plats on a scale of 1 to 2 500, follow. The contours are entered for every 5 m. elevation, and are drawn in a striking color, for instance, red, and every fifth contour is drawn heavier. In the plats of 1 to 2 500, roads, watercourses, buildings, the limits of built-up localities, or other important limits are now entered, relatively elaborated, and, as far as necessary, also indicated by written notes. Furthermore, the high water-marks on bridges and buildings or other places are written down in blue; so, too, the width and height of every existing bridge and of every culvert is given. In the plat are also indicated, by suitable notation, all unusual topographical details, as the existence of rock masses, the strike and dip of rock strata, slides, swamps, springs, quarries, pits, etc., which are of importance in the study of the location. A contour map made up in this way on a scale of 1 to 2 500 forms an excellent basis for the study of a general location and for the calculation of the cost of construction of the railroad.

To give a description of the study of the general project would carry us too far. But it must here be emphasized, that the line selected must surpass all its competitors in best adapting itself to the configuration of the land, and that the final result must be the unquestioned designation of that line as above all others the one which can be advanced as the most practicable. It is to be further remarked that the staking out of the line in the field is not necessary in the preliminary survey; it should even be avoided, as all facts can be taken from the map, and only in the latter is a superficial study possible. The transferring of the line to the field has no purpose; it may even injure the progress of the whole enterprise in that the adjoining property-owners are put in a position to speculate with their property.

Along with the execution of the preliminary work, the general estimate of cost is to be made, and the previously reported statement of the needed capital is to be corrected and supplemented. The route is finally to be put down in a map on a scale of 1 to 10 000; and a profile on a scale of 1 to 10 000 for distances and 1 to 500 for heights is to be made. Of the larger structures and of the track and switch work of

the yards, sketches are to be made for estimating their cost. Preliminary surveys, made in the above comprehensive manner and offering most certainly the best practicable solution, cost, according to the writer's experience, from 100 to 200 marks per kilometer.

Of all the preparatory work for the construction of the road, the preliminary survey is the most important of the engineer. If carried on in the proper manner, there is no danger that the location of the road must be later designated as a failure. Still, the detailed work to be described hereafter is also important and must likewise be carried out with a care corresponding to its purpose.

3. *Detailed Survey.*—This rests on the preliminary surveys, as these were based on the general investigations or reconnaissance. They constitute a further step towards arriving at the plan of the road. For this purpose the location of the line must be examined in greater detail, for which again plats on a larger scale are necessary. The next duty of the engineer consists in making surveys, and from these to prepare study maps which shall contain everything that is necessary for the study of the detailed project. A suitable scale for these study maps is 1 to 1 000. From the preliminary survey the approximate location is known. The detailed study of the project requires an exact survey of a strip of land from 100 to 200 m. wide in which the smaller width is to be taken for heavily sloping land, the larger for flat land.

As in the preliminary survey the barometer was mentioned as the instrument best adapted for the work, so for the surveys for the detailed work the tachymeter is best adapted, that is, a theodolite furnished with stadia wires.

The available force of engineers and assistants is divided, in tachymeter measuring, into small parties. Each party consists of two engineers, a recorder, a boy for holding the umbrella and for giving signals, and two or three rodmen. For the equipment of each party there is necessary, a tachymeter, with tripod and hood, a plummet, an instrument umbrella, a camp stool, a tape, two or three telemeter rods with plummets or pocket levels and stakes for securely setting up the rods.

The field work begins with laying out a traverse line which approximately follows the proposed line. The levels of the intersection points of the traverse are exactly determined and serve for all further work

as bench marks; consequently, they are to be fixed as securely as possible.

When the traverse line is staked out, secured, measured and leveled, it is plotted on a scale of 1 to 1 000, and the real tachymetrical survey then begins. In the work, one of the engineers of each party is stationed at the instrument, takes the readings, calls them off to the recorder who stands beside him, and has the umbrella boy give the necessary prearranged signals to the other engineer who is with the rodman, to give them the necessary directions. The second engineer carries the field book and records in it all the notes of the determined and consecutively numbered stations, and supplements it by intermediate distances which are necessary to work up the plot.

For the rapidity and usefulness of the tachymetrical measurements it is important to keep in view that the heights of the land must be obtained from comparatively few well-determined stations. By means of the tachymeter every desired point of the field can be quickly determined with regard to position and elevation; therefore the capability of the tachymeter is very great. According to the writer's experience, it may be asserted that practiced engineers in a field with not too many obstructions can, in one full working day, determine about 600 points.

The calculation of the tachymetrical stations, in other words, the reckoning of the distances from the instrument stations as well as the elevations, may be made by means of tables, or by logarithmic slide rules, or by the tachymetrical scales, based on graphical methods of Engineer Teischinger * or of Engineer Puller.† Since by the use of the tachymetrical sliding rules almost all calculations can be avoided, and the scale directly shows the elevation and horizontal distance, the reckoning with the two tachymetrical slide rules is to be preferred in extended surveys above all other methods, as the most reliable, most convenient and most rapid.

For plotting the notes, the sheets with the plotted traverse line on a scale of 1 to 1 000 are used. The plotting is started from the traverse station corresponding to instrument stations by means of protractors. In this way a map is developed on which, finally, contours of 1 m.

---

* Described in No. 4, 1883, of the "Zeitschrift des österreichischen Ingenieur u. Architekten Vereins."

† No. 4, 1888, of the "Zeitschrift des Architekten u. Ingenieur-Vereins zu Hannover."

difference in elevation may be sketched. Every fifth contour is drawn more heavily than the rest. As a matter of course, the map must show all determined points with their elevations, all objects necessary for the detailed location, roads and water-courses, bodies of water and flood points, buildings, bridges and culverts, farms, important boundaries, strike and dip of rock strata, rock masses, slides, swamps and moors, and all must be plainly described. In order to judge after the plotting, whether the surveyed and plotted territory is sufficient for the study of the location, it is necessary to lay out a preliminary line. If it then becomes apparent that the spread of the survey is not sufficient, supplementary surveys are to be undertaken at once.

For the study of the detailed location, exact knowledge of the nature of the soil where the road is to be located is of importance. Therefore, test pits along the preliminary line are to be made in all the larger cuts and the nature of the soil and rocks determined, in order to decide what slopes are practicable, and what the cost of moving will be. For the investigation of the capability of the ground to carry weights, test-pits must also be made at the base of high embankments and at places where large structures are to be located. The test-pits are likewise to be indicated in the map, and the result of the examination of the pits is to be noted on the edge of the map.

By this time the field work may be considered completed, and the engineer, aided by the study map on a scale of 1 to 1 000, proceeds to a thorough study of the location. All requisite notes he takes from the maps on which by various trials he seeks the most practicable location of the road. As necessary, he can take every required profile or cross-section from the map and can make the earthwork calculations. From the notes of the map he is also able to design and estimate on all the structures. Thus the detailed location of the road and the detailed estimate are arrived at without the necessity of locating the line of the field, to which favorable circumstances especial attention will hereafter be called. The study is made from the maps of 1 to 1 000, and is also laid out on this scale. Copies of the maps are made, and the location is entered on them. The scale is large enough to indicate also the adjacent ground. For a general view of the whole road, the scale of 1 to 1 000 is, however, too large ; therefore, it may be suggested, as it is often done, to prepare, besides, a general plan on a scale of 1 to 2 500, which is best done by photo-

graphic reduction. These maps will contain the complete presentation of the road, and are supplemented by a superscribed profile of the line on a scale of 1 to 2 500 for the distances and 1 to 250 for the elevations.

Detailed surveys, which are made in the manner above described, cost, according to the writer's experience, from 1 000 to 2 000 marks per kilometer.

4. *Field Location and Preparation of Expropriation Plans.*—The next work of the engineer is the transferring of the line to the field, in accordance with the location, as made on the plats of the detailed surveys on the 1 to 1 000 scale. The staking-off starts from the traverse line given in the field and in the maps. According to the accuracy of the maps, it is easily found that the line as transferred to the field corresponds to its location as given in the plats. The length of the line in the field will, however, always differ somewhat from the plotted line; still, never so much that the general map (scale 1 to 2 500) becomes useless. The division of the road, doubly measured in the field for the sake of certainty, is afterwards distinctly shown in the plats of 1 to 1 000, and is made the basis of the construction.

After the line has been staked out, numbered and secured by reference points, a profile of it is made by connecting with the bench-marks of the traverse line. This work is followed by the cross-sectioning at right angles with the line. Consideration of the suitable location of the cross-sections must be had during the staking out of the line, and it must be remembered that the exactness of the earth-work calculations depends, not on the number, but on the correct position, of the cross-sections. These are intended only for the construction of the comparatively narrow roadway, and are, therefore, to be extended only for short distances on each side of the line. The drawing of the profile is made with most satisfaction on the scale of 1 to 2 500 for distances and 1 to 250 for height, while the cross-sections are made in undistorted form on a scale of 1 to 200. Both profile and cross-sections are provided with the notes of the survey and are utilized to arrive at the earthwork calculations necessary for the immediate construction of the road.

The transference of the line to the field, just described, is followed by the measurement, plotting and finishing of the property plans on a scale of 1 to 1 000 and the preparation of the lists for the acquisition

of the property. The property plans are surveyed along the tangents of the line and are connected with adjacent property.

Before the construction of the road is begun, it becomes necessary again to subject the detailed location to another examination, and at places to improve and supplement it. This is followed by the preparation of working drawings, specifications and the formulating of contracts, etc. But this work is no longer to be counted a part of the survey of the road, but rather of the construction. It may, therefore, be assumed that the survey closes with the measuring and preparation of the expropriation plans. In the case of each of the three previous divisions of the survey, the approximate cost of the work for 1 km. of road was given at the end. So here, too, it is to be stated that the staking out of the line and the preparation of the expropriation plans, as still belonging to the survey, together are to be estimated at about 400 to 800 marks per kilometer.

The total cost of the survey would add up, according to the preceding figures, about as follows :

	Cost of 1 km. of road.
General investigation.....	20 to 40 marks.
Preliminary survey.....	100 " 200 "
Detailed survey.....	1 000 " 2 000 "
Field location and preparation of expropriation plans.....	400 " 800 "
Total cost of survey	1 520 to 3 040 marks.

That is, properly and thoroughly conducted surveys for railroads cost according to smaller or greater difficulties, under mid-European conditions, about from 1 500 to 3 000 marks for each kilometer of road.

With this the writer ends the discussion of a practicable method for making surveys for railroads, as proposed in the introduction. Basing his opinion on experience, he is convinced that those engineers who pursue it will soon appreciate the great advantage of the method by which we proceed step by step from the general to the particular. The investigations are accomplished in a quiet and satisfactory manner, and, with the least competency of the chief engineer, a failure is completely avoided. In conclusion, let us make a short freview of the method of work, and show in a few words how surveys or railroads are contrary to the accepted rule, still often pursued in an impracticable manner.

In an abridged form, the writer proposes the following rules for surveys for railway locations :

Firstly.—General investigations are to be made, which must cover a large territory containing all possible alternate lines. For this purpose a review map of 1 to 100 000 is prepared, in which the topography is represented and in which all important elevations are to be shown. Result; proposal of various alternate lines with estimate of cost of construction and operation of the road.

Secondly.—General Surveys.—The alternate lines suggested by the general investigations are more carefully examined by general surveys (preliminary). For this, surveys of large stretches of land and study maps with contours, on a scale of 1 to 2 500 or 1 to 5 000, by means of aneroid barometers, are made. Study of the general project in these maps and presentation of them on a scale of 1 to 10 000 for a ground plan, with a profile on a scale of 1 to 500 for height. The line is not transferred to the field. Results of the preliminary survey—selection of the most practicable location, general plan on given scale, general estimate of cost with reliably sufficient total cost and estimated income of the road.

Thirdly.—The Detailed Surveys.—The general line is more closely studied, its most practicable location still more accurately determined. For this, surveys by means of the tachymeter, of a strip of land from 100 to 200 m. wide, are made. Exact maps or plats (study maps with contours) on a scale of 1 to 1 000, soil investigations, etc., are made. Study of the detailed line in the above-mentioned maps of 1 to 1 000, and, as in the case of the general survey, without staking off the line in the field. Drawing of the detailed route in the maps of 1 to 1 000, as also for general review purposes in the maps of 1 to 2 500, to which is added a profile of 1 to 250 for heights. Results of the detailed surveys—exact determination of the most practicable location, detailed plan of the same and adjacent territory, detailed or principal estimate of the cost of the road.

Fourthly.—Field Location and Preparation of Expropriation Plans.—This division comprises the transferring of the line into the field, as determined in the exact plates, measuring of length and elevation of the located line, measuring and drawing of short cross-sections, indicating of the line in the cross-sections and profile, further testing and supplementing of the route; finally, measurement and preparation of the

property maps and making list of properties to be acquired. Result: Detailed and thoroughly prepared route of the road for those intending to construct it, the line of which has been transferred to the field.

It is to be added that the foregoing rules prescribe the measurement at first of general, then of plots of gradually increasing, exactness, in which the choice of lines may be made, and their study may be accomplished; whereas, the staking out of the line in the field and the measurement of profile and cross-sections cannot be undertaken till the end, and then only when the exact location of the line in the plots is finally determined. This will not only avoid the premature and unnecessary transferring of the supposed line to the field, and the making of unnecessary cross-section measurements, but it will especially meet the danger of locating in the field and building accordingly a line lacking previous comprehensive and thorough examination and investigation. This danger is always present, if the chief engineer has transferred to the field any line, according to his views perhaps the most practicable one, without having previously investigated it first in general, then in detailed, maps. Unfortunately this still frequently occurs. It is thought that dependence can be placed on a practiced eye, on traveling impressions, etc. It is intended perhaps also to greatly simplify the procedure of the surveys, and it is hoped to attain the result more rapidly, if the trouble of the preparation of comprehensive maps and the examination of the lines by means of them is dispensed with; in short, it is assumed that the best location can be obtained without long investigation, and acting on this supposition the line is located at once in the field. The line is measured, cross-sections are measured and drawn, and the project is worked up according to the location in the field. Thus the unfortunate step to an unfavorable solution is made.

It soon becomes evident that the line as located in the field is not altogether practicable. Then adjustments of the line within the limits of the cross-sections are attempted and if these get too far from the original line, nothing remains but to partially stake out a second trial line and to repeat the measurements and calculations for this one, again without good results. In this way adjustments and new trial lines follow one another, until finally a practicable route is developed. Practicable it may be, but who will vouch for it that it is the most practicable of all possible routes? No engineer who has made his

surveys in the faulty manner just described can say that. He has no idea whether the road could or could not be carried out in another location and perhaps very much cheaper, outside of the reach of his limited survey. It may even be asserted with certainty, that by his procedure he has not attained the result that might have been attained. The road, as nothing better is known, is brought to construction, and costs much more than it would cost, if its location had previously been properly examined on the maps and plots, step by step, first in general and then in detail and in a thorough manner, according to the given rules.

The surveys for railroads should, therefore, not be regarded lightly, and any movement toward staking out a supposed practicable line, without previous and through investigation from comprehensive maps should be especially guarded against. In most cases success in finding the location which is the most practicable, and which, when constructed, costs comparatively least, does not follow from too early a location in the field.

The cost of thoroughly prepared surveys is seldom more than the cost of defective surveys which rest on a line too soon located in the field, and the difference disappears when compared with the amount which is saved by a practicable location founded on good surveys.

There may be very simple cases in which one can proceed directly from the general study to the field location. These cases are, however, rare, and the writer would advise his colleagues to do a little extra work in the thoroughness of the surveys rather than too little. Good surveys pay well in all cases. Most dangerous to success is it, however, when the chief engineer undertakes to shorten even the reconnaissance, and before making the latter, if such is possible, endeavors to lay off a line in the field.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

620.

(Vol. XXIX.—August, 1893.)

A NEW METHOD OF CALCULATING CROSS-SECTIONS OF ROADS AND RAILROADS.*

By FRANCISCO DA SILVA RIBEIRO, Director of Public Works, Aveiro, Portugal.

Translated from the French by FOSTER CROWELL, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the calculation of cross-sections of roads and railroads strict accuracy is an impossibility, whether we plot them and determine the areas rigorously, or whether we obtain the areas from diagrams prepared by graphic methods; because the basis of the calculation, the shape of the ground, cannot be given exactly, owing to the innumerable deviations in the outline of the leveling.

* *Note to the English reader by the translator.*—This method of computing cross sections is only applicable to measurements made with the cube unit; in connection with American and English practice it would be necessary to have the diagram verticals at intervals of 1 yd. and the scales plotted to yards and decimals.

Wherever the metrical system is used the great advantages of the method are manifest. —F. C.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

The best practice is therefore the most expeditious one that will give us a sufficiently close approximation, and from this point of view our system, proved by long experience, appears to be entirely satisfactory. In effect our diagrams can very easily be drawn, for each different width of roadbed and inclination of the slopes, so as to furnish by simple readings the widths for the expropriations and slope distances, both at the regular stations and intermediately, and at the same time the partial areas the sum of which is the total area of the cross-section; the inclination of the ground may be regular or irregular. These, then, are all the conditions necessary for simplicity and completeness.

The plotting of the diagram is accomplished in the following manner:

Let $a\ b\ c$ (Fig. 1) be any half cross-section, divided by vertical lines at intervals of 1 m. and intersected by the center line of the road.

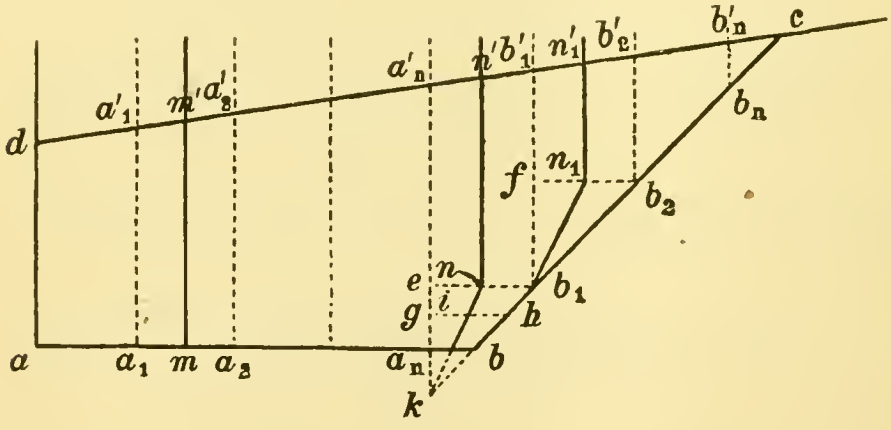


FIG. 1.

We will designate by $a_1 \ldots\ldots a_2$ the feet of the verticals intersecting the platform (formation level), and by $b_1 \ldots\ldots b_2$ those of the verticals which cut the slope.

In general, the surface line determines the figure of the rectangular trapezes such as $a_1\ a'_1\ a'_2\ a_2$; the pentagon $a_n\ a'_n\ b'_1\ b_1\ b$; the trapezes, of the form $b_1\ b'_1\ b'_2\ b_2$, and the triangle, $b_n\ b'_n\ c$, wherein the height is less than, or equal to, 1 m.

The areas of the rectangular trapezes, whatever may be the surface-line, are obtained correctly by means of the median lines $m\ m'$; so that if we measure by scale each one of these lines, starting from zero on

$a\ b$, we may obtain the total area $a\ d\ a'_n\ a_n$, by adding together all the readings of the amounts given by the scale.

The pentagon and the trapezes on the slope can be resolved into two parts, one of which is a rectangular trapeze $e\ a'_n\ b'_1\ b_1$ or $f\ b'_1\ b'_2\ b_2$, given by the mid height $n\ n'$ or $n_1\ n'_1$. It now remains for us to determine the areas contained in the trapeze $a_n\ e\ b_1\ b$ and in the triangles $b_1 f\ b_2$, for which we employ an approximative process.

Considering the trapeze let us assume—

a the constant side, $a_n\ b$ of the successive trapezes $a_n\ b\ h\ g$;

x the variable height, $a_n\ g$ of the trapezes;

A their surface;

t the natural tangent of the slope-angle from the horizontal;

We have $g\ h = a + \frac{x}{t}$ and it follows:

$$A = \frac{2\ a + \frac{x}{t}}{2}\ x$$

or

$$x^2 + 2\ a\ t\ x = 2\ A\ t.$$

We deduce from this equation—

$$x = \sqrt{a^2\ t^2 + 2\ A\ t} - a\ t.$$

By adopting a scale of $\frac{1}{500}$ we can readily estimate to $\frac{1}{200}$ of a cubic meter. It will suffice now for us to substitute $A = .1\ .2\ .3\ \ldots\ldots\ldots$ up to the value—

$$A = \frac{(1 - a^2)\ t}{2}$$

corresponding to $x = (1 - a)\ t$.

The successive values of A are to be laid out upon the median line $n\ k$, the point k being the intersection of the slope-line with the vertical $a_n\ a'_n$.

For the triangles $b_1 f\ b_2$, we make $a = o$ in the preceding formula, and obtain— $x = \sqrt{2\ A\ t}$,

and the limiting values of A and of x

$$A = \frac{1}{2}\ t \text{ and } x = t$$

we lay out these values on the median lines $n_1\ b_1$.

In this manner wherever the surface-line cuts the median lines $n\ k$, $n_1\ b_1$, we take for the areas of the respective figures the numbers inscribed upon those lines. The errors are insignificant.

We will next examine the case where the platform $a\ b$ is crossed by the surface-line.

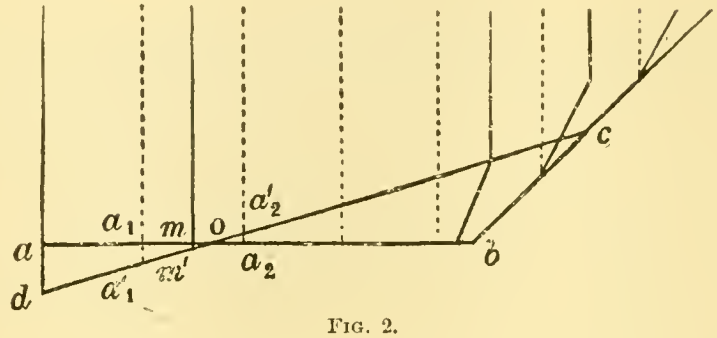


Fig. 2.

Besides the areas previously considered we find the triangles $a_2\ a'_2\ o$ and $a_2\ a'_2\ o$. We may admit approximately that the first is represented by the side $m\ m'$ shown on the corresponding scale, and consider the second null. In effect the greatest amount of this error is when the point o coincides with m; this applies both to fill and cut. For if we designate by i the surface inclination, we find in this case—

$$a_2\ a'_2 = .50\ i$$

and triangle $0\ a_2\ a'_2 = .25 \times .50\ i = .125\ i$; a negligible quantity.

We have now the necessary elements for constructing the diagram.

Upon the axis of the road, and also at a distance of 10 m. (by scale) therefrom (see Fig. 3), we lay out the scales intended for the elevations on the axis and the inclination of the ground. The line of the platform (subgrade line) is also furnished with a scale for the widths of the expropriation. The slope $b\ c$ may have another for the lengths as regulated or as they may occur.

If we employ quadrille paper (paper ruled in squares) this last scale may be obtained from the vertical by means of values of x deduced from the equation—

$$x^2 + \frac{x^2}{i^2} = D^2,$$

or

$$x = \frac{D}{\sqrt{1 + \frac{1}{i^2}}}.$$

Finally we remark that the section of the ditch for draining the surface of the cut is given by diagram.

The diagram (Fig. 3) is designed for a roadway of 6.6 m. (21.65 ft.) in width between ditches. It gives the surfaces of cut, the width of

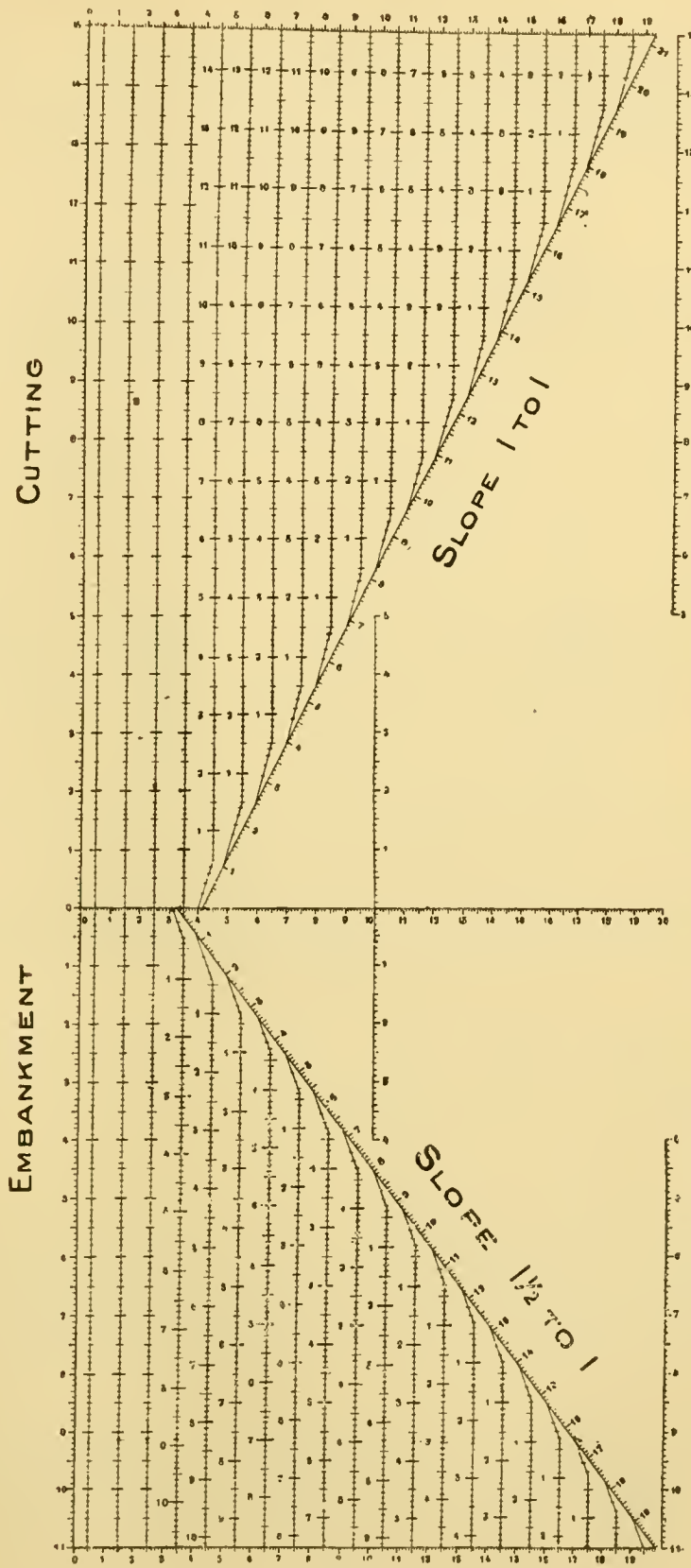


DIAGRAM FOR CALCULATING AREAS OF CROSS-SECTIONS OF ROADS AND RAILWAYS.

FIG. 3.

ditch being .9 m. (3 ft.) and the slope-angle is 45° (1 to 1); the surfaces of the fill have a slope of $\frac{2}{3}$ of height for 1 of base ($1\frac{1}{2}$ to 1). The vertical scale is twice the horizontal.

Making in our formula—

$$a = .2 \text{ and } t = 1 \text{ for the cutting,}$$
$$a = .3 \text{ and } t = \tfrac{2}{3} \text{ for the fill,}$$

we obtain the following data to be used in laying out the median lines:

Values of A.	Values of x.			
	Cutting.		Embankment.	
	Trapeze.	Triangle.	Trapeze.	Triangle.
0.10	0.290	0.447	0.216	0.365
.20	.463	.632	.354	.516
.30	.600	.775	.463	.632
.303	.....	.....	.467	.....
.333	.....	.....	.....	.667
.40	717	.894	.564	.734
.48	.800	.....	.....	.....
.50	.820	1.000	.664	.834
1.00	1 320	2.000	1.164	1.334

The values of the coefficient of the length of the slope are—

$$\frac{1}{\sqrt{1 + \frac{1}{t^2}}}$$

for the cutting..... $\sqrt{\frac{1}{2}} = 0.7071$

for the embankment..... $\sqrt{\frac{2}{13}} = 0.5547$

In order to avoid having the scale of the inclinations encroach upon the slope we have set a part of it at a distance of 20 m. from the axis; the plotting apparently doubles the respective slopes used in the diagram.

The readings on the median lines may be made by stretching a thread with pins or with weights, furnished with hooks at the base. This method enables us to calculate as many as 200 cross-sections in a day.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

621.

(Vol. XXIX.—August, 1893.)

ON THE GAUGES OF RAILROAD TRACK IN GENERAL, WITH SPECIAL CONSIDERATION OF NARROW-GAUGE RAILROADS.

By E. A. ZIFFER, C. E., of Vienna, Austria.*

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Translated from the German by WOLFGANG G. TRIEST, Jun. Am. Soc. C. E.

Evolution of the Railroad Gauge.—Many text books, pamphlets and engineering papers contain a bountiful supply of scientific discussions, based only partly on practical experience, on the selection of the gauge which generally exercises a determining influence on the construction and running expenses as well as on nearly all proportions of a railroad. It is, however, somewhat difficult to obtain from the existing

* Ex-Technical Director and Member of the Board of Directors of the I. R. Lemberg-Czernowitz-Jassy Railroad Company; President of the Bukowina Local Railroads; Vice-President of the Kolomeaer Local Railroads; Member of the Board of Directors of the Lemberg-Belzec (Tomaszoiv) Railroad and of the I. R. Ostrau-Friedland Railroad.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

material the nucleus of the considerations at issue, especially as regards the newer creations, the narrow-gauge railroads, and thus find new points of view for this most important subject.

Before approaching this question more closely, which is not only purely technical, but essentially an economic one, the writer may be permitted to present a historic retrospect on the evolution of the railroad gauge.

The selection of the gauge of 4 ft. 8½ ins. (1.435 m.), measured between heads of rails, which George Stephenson took in 1825 for the first locomotive, built at his Newcastle shop, for the first public railroad from Stockton to Darlington,* and in 1830, for the railroad from Manchester to Liverpool,† is not the result of technical considerations, but is only the adoption for railroad purposes of the gauge customary for road wagons in North England; it was accidental.

This gauge, sometimes wrongly named "German gauge," originated, therefore, in England. It was introduced as "Stephenson's gauge" into most European countries, and became international in 1886, at the international conference for technical units in railroads. It is designated as "standard" or "full gauge." In 1846 it had already been ordered, by Act of Parliament, for all English railroads then under construction or to be thereafter constructed, except for those in the counties of Cornwall, Devon, Dorset and Somerset.

It has been recognized that this gauge is more in accordance with the ordinary demands of freight traffic because with its use the loading capacity of the freight cars, conditional on the gauge to a certain degree, corresponds better to the customs of commerce than with the 7-ft. (2.134-m.) gauge. The latter was introduced by Isambard Brunel,‡ on the London-Bristol division of the Great Western Railway in 1836. The origin of the different gauges of Great Britain is due to the fact that engineers have partly followed Stephenson's example, and partly that of Brunel. With the primitive status of the track and rolling stock of those days, the broadest possible basis

* September 27th, 1828, must be regarded as the birthday of the present railroad system, when the first passenger train was drawn by a locomotive over the railroad from Stockton to Darlington, 41 km. long, at a speed of 10 km. per hour. This road had, however, been in use since 1825, but until that day had been used for the transport of coal and ore only, tho same as the other railways of that time, which were mostly operated by horses.

† This was the first railroad built from the start for a general passenger and freight traffic. It was opened on September 15th, 1830.

‡ Dr. Röll's Encyclopädie d. ges. Eisenbahnwesens (Biographie Brunel), II Band, 1890.

seemed necessary for stability, as it was supposed that the stability of the car and the speed attainable would increase with the angle of stability, viz., the angle formed by lines drawn from the center of gravity of the car to the heads of both rails. This consideration may be regarded as outgrown by the present high development of iron construction and manufacture. The scope of the mistake of having taken several gauges was, however, not realized, until the railroads with varying gauges were so enlarged as to join each other. Then it became evident that differences of gauge rendered the uniform operation of such a system of railroads entirely impossible and entailed such disadvantages as to compel the adoption of a standard gauge.

The Development of Gauges in Different Countries.—In spite of this, there were in use until recently, in England and Wales, the following different gauges besides the standard gauge, viz.: 1 ft. 11½ ins. [(0.597 m.) Festiniog and North Wales Railway], 3 ft. (0.914 m.), 3½ ft. (1.070 m.) and 4 ft. (1.220 m.); in Scotland, 4 ft. (1.220 m.), 4 ft. 7¾ ins. (1.416 m.), and 4 ft. 7⅝ ins. (1.413 m.); in Ireland, 3 ft. (0.914 m.), 4 ft. 8 ins. (1.422 m.), and 5 ft. 3 ins. (1.600 m.). It must be mentioned, however, that these different gauges are in operation only on secondary and tramcar lines and on industrial railways. The Great Western Railway has entirely abandoned the broad 7-ft. (2.134-m.) gauge, by changing to standard gauge, in May, 1892, its last broad-gauged division from Exeter to Falmouth, 270 km. This feat was accomplished by 5 000 workmen in 31 hours, including a Sunday, so that there was little interruption in the operation of the road. The narrow-gauge railroads in the large shops at Crewe and Chatham with a gauge of 1 ft. 6 ins. (0.460 m.) may also be cited, and, as a curiosity, the transportation road of the iron works of the Furness-Abbey Company, which has a miniature gauge of only 8 ins.

For Ireland the gauge was fixed at 5 ft. 3 in. (1.6 m.).

France adopted a standard gauge in 1828, and the majority of its railroads have been built with a gauge of 1.5 m. between rail centers. This is a very inconsiderable deviation from normal gauge, as the gauge will vary between 1.44 and 1.45 m., according to the width of rail heads. At present, a clearance of 1.44 m. between rail-heads is exacted. The movement to make narrow-gauge roads acknowledged members of the European railway system dates from the year 1851, but the narrow gauge was first used by the engineer Sartiaux, in 1874,

on the passenger and freight railroad from Neuilly-en-Thelle to Beaumont. This line contributed largely to the development of the 1-m. gauge railroads, thanks to the energy of Civil Engineer Level.*

Narrow gauge was not used on a main line (*chemin de fer intérêt général*) before 1885, when it was taken for the railroad from Châteaumeillante la Guerche to Sancoins la Peyrouse. The law of 1880 did not fix the gauge, but discriminated between railways over which the rolling stock of the trunk lines could or could not pass.

The specifications for railways, however, provide for gauges of 1 m. and of 0.75 m., in addition to standard gauge, and thus enable the roads to obtain different gauges suitable to different demands. The above regulation was suspended in 1891, and, besides standard gauge, only gauges of 1 m. and of 0.6 m. were declared admissible. The latter has been recently chosen for secondary (*chemins de fer intérêt local*) and for strategic railways. Very recently (August, 1892) the 0.8-m. gauge was chosen for the secondary railroads of the Department of the Ardennes. The industrial railways also use gauges of 0.5 m. and upward ; finally, the Lartigue system, a one-rail railroad, consequently a road without any gauge, should be mentioned. A charter has been given for a railway on this system from Fleurs to La Panissière, 17 km., and the right of eminent domain was declared for it.

The Franco-Algerian Railway had adopted the gauge of 1.055 m. in 1872; but, since 1877, the 1-m. gauge has been in exclusive use in Algiers. In 1861 the French Government had ordered an "*enquête,*" which should furnish a strong stimulus to the building of secondary railroads. Considerable merit is due to Eugen Flachat,† one of the most prominent members of the commission, who advocated the use of narrow-gauge roads.

Italy has generally introduced the standard gauge of 1.445 m., the same as France, but uses also gauges of 0.95, 0.85, 0.8 m., and of 0.75 m. for the secondary railroad Agropoli-Niercato-Cilezito (Salerno). The first railway was opened in 1839. The industrial railroads and steam-tramroads have gauges of 0.70, 0.95, 1.0, 1.1 and 1.5 m. besides the prevailing standard gauge. The St. Léon Railway in Sardinia was given the gauge of 0.76 m. in 1865 ; besides this, the gauges of 0.85 and 0.95 m. are found. The narrow-gauge Sicilian railroads use the 0.95-m.

* Chemin de fer intérêt local de Neuilly à Beaumont, Sartiaux, 1874.

† Dr. Röll's Encyclopädie d. ges. Eisenbahnwesens, IV Band, 1892.

gauge. The Secretary of Public Works, Finali, declared, in 1891, in introducing a law for secondary railways into Congress, that the above "*enquête*" had unqualifiedly given as its opinion, that the 1-m. gauge had to be considered an extreme upper limit for secondary railroads.

In Belgium the first railroad was opened for public traffic in 1835. Standard gauge predominates, but the 1-m. gauge has been adopted for the local railroads, except those joining Dutch secondary railroads with a 1.067-m. gauge and the railway from Antwerp to Ghent, with a gauge of 1.150 m.

In Germany the first railroad, from Nürnberg to Fürth in 1835, and the Leipzig-Dresden Railway, were built at once to normal gauge, which has since been adopted for all German main railroads. The Mannheim-Basel Railway in Baden used alone the Irish gauge of 5½ ft. (1.60 m.), but altered it to standard gauge from urgent considerations of traffic ; this was done from 1854 to 1855. The first railroad with all the characteristics of a secondary road in its construction and operation was the Bröhlthal Railroad in the Rhine province, 33.6 km., built in 1862, with a gauge of 0.785 m. It was followed by the Gerhard Prinz Wilhelm coal railroad, 4 km., 0.725-m. gauge, opened in 1863, and by the Ocholt-Westerstede Railway in Oldenburg, 0.750-m. gauge. In 1878, the agricultural railroads were introduced with 1-m. gauge.

It was reserved for the Secretary of State, Baron von Könneritz, and for Privy Councillor von Köpke to build narrow-gauge (0.75 m.) roads in Saxony to a greater extent, in a length of 199.36 km. Most recently, also, other German States show a movement in favor of the gauges of 0.75 and 0.60 m. Besides these gauges, those of 1.00, 0.90 and 0.785 m. are used by secondary railroads, and the gauges of 1.00, 0.95, 0.90, 0.85, 0.79, 0.785, 0.78, 0.75, 0.73, 0.70, 0.68, 0.66, 0.65, 0.60, 0.58 and 0.54 m. are found in use on mining, industrial, agricultural and forestry railways. The German Railway Union has recommended the gauges of 1.00 and 0.74 m. for narrow-gauge roads in establishing the principles for the construction and operation of local railroads, and in the code of rules for German railways of minor importance. Exceptions are admissible only with authorization of the Government, under concurrence of the Imperial Railway Commission. Especial mention should be made of the Prussian law of July, 1892, for "Small Railroads" and private feeders and the issue of specifications of November

1892, which permit only the gauges of 1.00, 0.75 and 0.60 m. besides the standard gauge for all railroads operated by engines.

In Schleswig-Holstein the main lines use standard gauge, the secondary roads have 1.00 and 0.88 m. gauge.

In Austria, the charter for the first railroad, from Linz to Budweis, was granted in 1824. It was opened partly September 30th, 1828; was completed August 1st, 1832; and was originally operated by horses. This line was followed by the Linz-Gmünden Railroad, opened May 1st, 1836; its division, Lambach-Gmünden, was changed for operation by locomotives in 1854; while the Linz-Lambach division was abandoned in 1859. The Lambach-Gmünden Railroad was therefore the first narrow-gauge road with a gauge of 3 ft.7½ ins. (1.106 m.).

Later roads were all built to standard gauge, and only the Bosnian campaign opened a larger field to the 0.76-m. gauge and brought it into use for main lines, thanks to the War Department and to the Secretary of the Treasury, von Kállay. At present, in Bosnia and in the Herzegovina, the Doberlin-Banjaluka Railroad, 101.5 km., constructed by the Turkish government, and the junction road from Bosnian to Slavonian Brood, are built to standard gauge; the Bosna Railroad and the Bosnian-Herzegovinian State Railroad, with their adjoining transportation and industrial roads, in an aggregate length of 435 km., use the 0.76-m. gauge. Gauges of 0.550, 0.700 and 0.865 m. are also in use on transport and mining railways.

In 1888–89 charters were given to the following local railroads: the Mori-Arco-Riva Railroad, the Salzkammergut Railroad and the Steyrthal Railroad; they have a gauge of 0.76 m. and are now being successfully operated. The Styrian State local railroads, 0.76-m. gauge, were granted charters in 1890–91 and are now partly under construction, partly in operation. Other local railroads have been built with 1.0-m. and standard gauge.

In Hungary the principal roads have been built to standard gauge; for local railroads, the gauges of 1.00, 0.95, 0.80, 0.79, 0.76 and 0.75 m. are used besides standard gauge, the smaller gauges being mainly taken for coal and mining roads. The first 0.60-m. gauge road was the private cattle railroad from Berzowa to Lalasincze, 3.5 km., built in 1886.

Russia uses (the standard-gauge roads west of the Vistula excepted) a gauge of 1.524 m., which is at variance with all other great

European railway systems; this is also due to chance. The builder of the first Russian railway, from St. Petersburg to Zarskoe-Selo, the Austrian professor, Franz Anton Ritter von Gerstner*, in 1837, chose the gauge of 1.820 m., so as to construct powerful locomotives, oscillating little at high speeds, and to obtain a more favorable proportion between effective and dead load. The American engineer, Major Whistler, called as expert consulting engineer for later Russian railways, selected, however, the gauge of 5 ft. (1.524 m.), and this has remained the Russian gauge, and has also been adopted for the railways of Finland. On some roads of minor importance the 3 ft.-6 in. gauge (1.067 m.) has been introduced, and for feeders of main lines, over which the rolling stock of the latter cannot pass, the standards of the Russian government, June, 1892, fix a gauge of 1 ft. $11\frac{5}{8}$ ins. (0.60 m.).

Holland had adopted standard gauge for the Amsterdam-Haarlem Railroad in 1839; later, the broad gauge of 1.93 m. was originated on the Amsterdam-Hague-Rotterdam Railroad from causes not evident, but it has been removed since. Besides standard gauge, the gauges of 0.750, 1, 1.067 and 1.750 m., are in use on local and street railroads (*lokaal spoorwegen*).

On the Dutch dependency, Java, the first railroad from Samarang, built in 1862, uses standard gauge as the exception only. The other railroads of Java have a 3 ft.-6 in. gauge (1.067 m.), which is there considered as "standard gauge."

Luxemburg uses standard and 1-m. gauge.

Switzerland has adopted standard gauge and opened its first railroad in 1844; on the mountain (rack and cable) and on tramcar roads, the gauges of 0.75, 0.80 and 1 m. are predominant.

Spain uses the standard gauge on a majority of its roads, but there still exists the Spanish gauge of 5 ft. 6 ins. (1.776 m.), called "wide" or "broad" gauge, in contradistinction to narrow and standard gauge. Very recently, narrow-gauge roads have been built with 1-m. gauge. The first railroad was constructed in 1844.

Portugal opened the first railroad for public traffic in 1854 with a gauge of 5 ft. 6 ins. (1.676 m.). Later, roads were built also with gauges of 1 and 0.90 m.

In Scandinavia, narrow gauge has found entrance on some principal railroads and is preponderating.

* Dr. Röll's Encycl. d. ges. Eisenbahnwesens, IV Band, 1892. Biographie Gerstner.

In Sweden and in Norway the first railways were opened in 1851 and in 1854 respectively. In Sweden, standard and 0.891-m. gauges have been generally used; besides these, gauges are found of 0.802, 1.067, 1.093, 1.188 and 1.217 m. During the last years, more than 300 miles of secondary roads of 0.6-m. gauge have been built on the system of Civil Engineer A. F. Hummel.*

Greece has been one of the later European States in railroad construction. Its first line, Athens to Piräus, opened in 1869, was standard gauge. For the Thessalian railway system and for the Attic Railroad, though main traffic routes, 1.0-m. gauge has been selected for economic reasons; these roads are partly under construction, partly projected only. The line from Diakophto to Kalarryta has 0.75-m. gauge.

Denmark uses standard gauge; its first road was opened in 1847.

Roumania opened the first line in 1870 and has standard gauge exclusively.

Servia has been one of the last countries to undertake the building of railways; it has adopted standard gauge, the first line having been opened in 1884.

Bulgaria. First railway was opened in 1866; all roads are built to standard gauge.

European Turkey completed its first railroad in 1860 and has adopted standard gauge.

The first railroads built in the United States of North America, in 1827, and in Canada, in 1840, had taken standard gauge, because the first locomotives were brought over from England. When, however, Brunel and his partisans called attention to the advantages of a broader gauge regarding an easier construction of the engines and a greater stability of the trains, standard gauge appeared to be too small, and the New York and Erie Railroad, the Canadian Trunk Line and the Ohio and Mississippi Railroad chose the 6-ft. (1.829-m.) gauge.†

Other roads also have used gauges of 5 ft. (1.525 m.), 4 ft. 8½ ins. (1.435 m.), 5 ft. 6 ins. (1.676 m.) and 4 ft. 10 ins. (1.473 m.), without going to the above extreme. Besides these, gauges of 1.449, 1.068,

* Wochenschr. d. öst. Ing. u. Arch. Ver., No. 2 und 3, 1891.

† The Grand Trunk Line, in Canada, in 1873, altered its system from broad to standard gauge in one day. A similar feat was performed by the Southern railroads of the United States, which changed their lines from a 1.525-m. gauge to 4 ft. 9 ins., almost identical with standard gauge. This alteration was perfected on a length of roads of 18 500 km. in the days from May 31st to June 2d, 1886.

0.915 and 0.763 m. exist. On the Southern roads the gauge of 5 ft. (1.525 m.) was predominant.

But the necessity of a uniform gauge soon became evident. Many roads were built to standard gauge, and finally a compromise gauge of 4 ft. 9 ins. (1.448 m.) was agreed upon for economic reasons. Extensive systems were altered to conform to it. This dimension does not tally exactly with standard gauge, but the small difference is not considered an obstacle to through traffic.

After standard gauge had superseded broad gauge in the United States, it began the contest for superiority with narrow gauge. In 1871 the report of the legislative committee recommended the latter in the following words: "Where industrial railroads alone are possible, the adoption of narrow gauge permits the outlay to be cut down about one-half, without decreasing the requisite efficiency."

R. F. Fairlie* declared before the British Railway Union in Liverpool in 1870: "Every inch added to the absolutely necessary width of the gauge increases the cost of construction, the proportion of dead load and the cost of passenger traffic. It consequently necessitates a higher tariff and diminishes the benefits of the road."

It must, however, be said that recently, since the introduction of trucks into the rolling stock, a movement in the opposite direction makes itself felt. The trucks allow curves to be passed, even of 27-m. radius without difficulty, as on the Manhattan Elevated Railroad in New York, and thus remove a principal argument in favor of the narrow gauge, viz., that it accommodated itself more easily to the formation of the country.†

Memorable is the 0.25-m. gauge of the line from Bedford, Mass., to North Billerica, 14 km. long.

In the Argentine Republic the first railroad was opened in 1857, in Chile in 1852, and in Peru in 1851; these roads were standard gauge and gauges of 5 ft. 6 ins. (1.676 m.), 1 m. and 0.763 m.

In Bolivia, the first railway was opened in 1873; the line from Antofagasta to Uyuni, 615 km., has been built to 0.76-m. gauge.

The first Brazilian railroads, completed in 1854, have a 5 ft.-3 in. gauge. Most roads use 1-m. gauge, however, which has also been taken for the Transandine Railway. Gauges of 1.40, 1.20, 0.95 and 0.60 m. are also in use.

---

* Dr. Röll's Encycl. d. ges. Eisenbahnwesens, III Band, 1891, und IV Band, 1892.

† Annales des Ponts et Chaussées, Août, 1892. Uniformité de largeur des voies ferrées aux États-Unis, par H. Rousseau.

In Venezuela, a 0.92-m. gauge has been built recently.

In Asia, the first railroads were built in the East Indies in 1853 with a 5 ft.-6 in. (1.676 m.) gauge, recommended by Simms. This gauge is called "Indian broad gauge" and is still prevalent. There are other roads with gauges of 4 ft. (1.219 m.), 3 ft. 3⅜ ins. (1 m.), 2 ft. 6 ins. (0.762 m.), and 2 ft. (0.610 m.); the last on the line from Illigori to Darjeeling. The gauges of 4 ft., 2 ft. 6 ins. and 2 ft. were chosen in each case for special reasons, and therefore need not be taken into consideration, so that only the 1.676 and 1 m. gauges remain as representative. The Indian government seems, however, to favor the broader gauge, which is to be used in building the system of the Bengal-Nagpur Railway, the Madras-Calcutta Railway, the line from Kurrachee to Delhi, and the strategic railroad to Afghanistan and to Beloochistan.

In Asiatic Turkey the Ardin and the Cassaba Railroads, the line from Mersina to Adana and the Anatolian railways have been constructed with standard gauge. For the Jaffa-Jerusalem Railroad the 1-m. gauge has been chosen, which will also be used on the proposed lines Mudassia-Brussa and Saint Jean d'Acre-Damascus.

The first railroad in China, 8 km., built by the English from Shanghai to Kangwan, was given a 2 ft.-6 in. (0.76-m.) gauge. The same is used on numerous mining roads in Peru, leading from the interior to the ports.

In Japan, the first railroad was constructed in 1872, and there are at present about 3 000 km. of railroads, all with a 3 ft.-6 in. gauge.

In Africa, the first road was built in Egypt, in 1856, with standard gauge. Gauges of 5 ft. 6 ins. (1.676 m.) and 3 ft. 3⅜ ins. (1 m.) are also in operation. The narrow-gauge road from Port Said to Ismaila, built by the Suez Canal Company, to join the Egyptian main line at Ismaila, has a 0.750-m. gauge. It will be opened shortly for passenger, baggage and express freight traffic; other freight is excluded. The Congo Railroad will also have the 0.760-m. gauge.

In Australia, we find three different gauges: 4 ft. 8½ ins. (1.435 m.) in New South Wales; 5 ft. 3 ins. in Victoria and partly in South Australia (railroads opened in 1854); 3 ft. 6 ins. (1.067 m.) in Queensland, opened in 1865; in New Zealand in 1863; in West Australia and partly in South Australia, opened in 1854. Among them, the 4 ft.-8½ in. gauge is predominant.

It cannot be doubted, however, that the disadvantages resulting from the difference in gauges for international traffic and military purposes will lead also in that country to the adoption of a uniform gauge.

Total Length of Operated Railroads and Amount of Invested Capital.—At the close of 1890, the total length of railroads in operation on the earth, according to the statistics, was 617 265 km. They are divided between the continents as follows:

America	331 417 km.	= 54%
Europe	223 869 "	= 36%
Asia	33 724 "	= 5.5%
Australia	18 869 "	= 3%
Africa	9 386 "	= 1.5%

On these roads—

Standard gauge is used by	74%
Broad " "	12%
Narrow " "	14%

The total capital invested in railroads was, at the end of 1890, 131 000 million marks, or an average of 212 100 marks per kilometer.

Beginning of the Movement in Favor of Narrow Gauge.—The movement in favor of narrow gauge began in reality only in 1869, after attention had been called to the great importance and value of narrow-gauge roads at the meeting of German architects and engineers in 1868. Until then, main lines had been built almost exclusively; these had to carry a large traffic and had to be constructed as perfectly as possible. Only towards the end of the eighties the building of roads of inferior importance was begun on a larger scale, to accommodate minor traffic. On these roads, called "railroads of second order," it became possible to materially reduce the requirements of main lines regarding construction and operation. But even the relief accorded to these roads of "second order" did not suffice to make them interest-bearing. The outlay for construction and operation is still too high and generally renders their earning capacity entirely insufficient.

Necessity for the Introduction of Secondary Railroads with Simple Construction and Cheap Operation.—It has become necessary to develop a still more simple mode of construction for these railroads and for their

* Archiv f. Eisenbahnw., 3. Heft, 1892.

rolling stock, and to adopt a less elaborate system of operation, in order to best meet possible local demands and to assist the different branches of industry. The object has been attained generally only by introducing narrow-gauge roads (local, secondary, vicinal* railroads), which may be classified as "railroads of the third order." Determining principles for such roads are the following : economical construction ; the utmost flexibility and freedom in the arranging of tariffs ; a curtailment of the jurisdiction of the Government as to public interests, especially regarding regulations of safety and precaution, as well as a simple system of operation and greatest possible independence. At the head of such enterprises must be placed men of purpose and experience, well acquainted with the economic and commercial condition of the districts in question, and in close touch with the people interested in the roads, which must be adapted as closely as possible to the requirements of local traffic. The above data and deductions show what a chaos still exists in the dimensions of the gauge, and prove how important it would be, especially for narrow-gauge roads, to agree on certain definite gauges.

Based on the existence of such a necessity, the writer will now proceed to the discussion of the question at issue, of the advantages and disadvantages of the narrow gauges, as its proper selection must be considered as a fundamental condition for economy in constructing and operating railroads of minor importance.

Advantages of Narrow-Gauge Roads in General.—Authorities, who for many years have occupied themselves with the construction and operation of narrow-gauge roads, regard as their advantages :

I.—Savings in construction.

II.—Savings in the purchase of rolling stock.

III.—Savings in operation.

Disadvantages of Narrow-Gauge Roads in General.—On the other side, some not entirely unprejudiced experts consider as supposed disadvantages, or at least as objections :

I.—That the secondary roads are of smaller capacity, able to accommodate only a light and limited traffic, and consequently of little value for the purposes of the War Department.

II.—That their operation is comparatively dear, and that the transportation of animals is impossible.

* Railroads built on the vicinal roads (country highways).

III.—That the difference of gauge entails many inconveniences at the junction stations.

Arguments on Narrow-Gauge Roads from the Standpoint of the Requisite Capital and of the Quality of Traffic.—Before discussing the above advantages and disadvantages, the writer must emphasize that, in his estimation, the construction of a secondary road is a financial question primarily. The amount of the necessary capital is a function of the cost of construction and operation, and these again depend on the requirements of the passenger and freight traffic.

The narrow-gauge roads are means of transportation of inferior importance, which must bear proper relations to the demands made on them. The selection of the gauge will, therefore, depend not only on the requirements, but also on the extent and quality of the expected traffic, and, further, on the capital obtainable, with especial consideration of the earning capacity of the proposed railroad line and of all local conditions. The narrow-gauge roads have consequently found entrance everywhere, where the conditions necessary for the building and operating of standard-gauge roads do not exist.

Justification of the Hitherto-Used Gauges.—Each of the gauges used hitherto has its advantages, its disadvantages and its justification. Where a great bulk of freight is received from a standard-gauge road, and where the proposed line which is to join it is short, a standard-gauge road may be advantageous in a favorable locality and under certain conditions. In a difficult location, where heavy gradients or sharp curves cannot be avoided at all or only at great expense, the narrow gauge becomes the more preferable, as the object to be attained is to connect, at a small outlay and through simply operated roads, with the international traffic, parts of the country economically retarded or remote from the world's interchange; to facilitate their supply of raw material and the distribution of their products, and to create new industries. Such roads play the rôle of a truckman; they carry goods to the large roads and receive goods from them for delivery. It can be said that the gauge may be as variable as the necessity for the construction of secondary roads.

Consequently, the secondary roads must not adhere to the present system of construction and of equipment, and must deviate considerably from the standards of construction as well as of operation of large roads. They take the place of country roads or tramcar lines in a

measure, and deriving their principal importance from the accommodation of local traffic, the cost must bear a proper proportion to its demands, in order to insure a suitable percentage of interest to the invested capital.

Principal Conditions for Secondary Roads and for the Selection of their Gauge.—A cardinal principle must be to build secondary roads at the smallest possible expense, and a narrow gauge, light motors and low speed must be chosen to accomplish this. The last will permit an installation inadmissible with railroads using higher speed. The proper selection of the gauge is an essential condition, but we shall consider only the gauges of 1, 0.75 and 0.60 m., which have been principally and successfully used.

Advantages of Narrow-Gauge Roads in Detail.—Regarding the above-mentioned advantages of narrow-gauge roads, it must be stated—

I.—Economy in construction is principally brought about by the faculty of narrow-gauge roads to adapt themselves closely to the formation of the country and to use steeper gradients and smaller radii. The progress made already in this respect is proved by the fact that in some countries the cost per kilometer has been reduced from 100 000 francs to 30 000 francs, that is, to less than one-third.*

The cost per kilometer of Belgian narrow-gauge roads, on which 1.0-m. gauge prevails, fluctuates between 16 000 and 25 000 francs for substructure and superstructure, including bridges, culverts, etc.; they average 3 430 francs for buildings, making a total of 28 430 francs.

The 0.75-m. gauge Gelder road in Holland cost 32 400 francs per kilometer.

The average cost of the Saxon narrow-gauge roads, 0.75-m. gauge, has been 57 500 marks per kilometer.

In Germany, there are open for public traffic 1 051 km. of narrow-gauge roads with gauges of 1, 0.90, 0.785 and 0.60 m. Besides, there exist 4 198 km. of mining, industrial, agricultural, forestry and other roads, not open to the public, with gauges of 1, 0.95, 0.90, 0.85, 0.79, 0.785, 0.78, 0.75, 0.73, 0.70, 0.68, 0.66, 0.65, 0.60, 0.58 and 0.54 m. The average cost of the former was 52 124 marks per kilometer, the receipts, 4 721 marks, the running expenses, 3 210 marks, or 68.01% of the receipts. The capital brought an average interest of 2.6 per cent. The

* The average cost of secondary roads in France, with an aggregate length of 3 150 km. was 113 000 francs, at the end of 1890. Of this total length 1 450 km. were narrow-gauge roads, mostly with 1-m. gauge.

most expensive narrow-gauge road was one in the Breslau Railway district, with 95 114 marks per kilometer; the cheapest was the line Strassburg–Markolsheim with 15 179 marks per kilometer. The average cost of private feeders (1 124 km.), operated with engines, was 61 499 marks, and of those operated with horses (502 km.), 32 806 marks per kilometer.*

On standard-gauge roads the radius of curves must not be less than 100 m., or very serious disadvantages will have to be encountered; while with 1-m. gauge, radii down to 60 m., with 0.75-m. gauge down to 40 m., and with a 0.60-m. gauge down to 20 m. may be used. These curves permit the formation of the ground to be followed and result in savings in earth and rock work as well as in masonry and bridge work. The advantage of sharp curves and of steep grades makes itself especially felt where public country roads are utilized. On these the track can generally be laid on their grade and alignment, and can be carried through the villages to their mines or factories.

Hereby there are brought about :

(*a*) *Savings in the Roadbed.*—These are, especially if the railroad needs a separate roadbed, savings in the acquisition of right of way and in the amount of grading and of masonry and bridge work. The size of depots and yards can be reduced. The bottom width of roadbed for cuts and embankments in the open road is 4 to 4.30 m. for standard-gauge secondary roads; while, with the three most popular widths of narrow gauge, it can be built in the following dimensions :

Gauge.....	1 m.	0.75 m.	0.60 m.
Bottom widths of roadbed	3.3–3.5 †	2.0–3.0 ‡	2.6–2.8 §

If retaining walls are used in cuts or embankments, the bottom width of roadbed may be further diminished about 0.20 m.

---

* " Statistik d. im Betr. befindl. Eisenb. Deutschlands, Betriebsjahr 1890-91. Berlin, 1891."

† In Austria-Hungary (1-m. gauge).....3.0 m.
In Austria-Hungary—Bosnia and Herzegovina (0.76 m.).....2.8–3.0 "

‡ On the Saxon Secondary Roads (0.75 m.).....2.95 "
" " Ocholt-Westerstede Railroad, Germany (0.75 m.).....2.00 "
" " Bröhlthal Railroad, Germany (0.785 m.).....2.51 "
" " Waldenburg Railroad, Switzerland (0.75 m.).....2.83 "

§ On the Décauville railroads:
(France and transoceanic countries) (0.60 m.).....2.50 "
On the Scandinavian Local Railroads (0.60 m.).....2.80 "
" " line from Louisenhain to the Warthe in Germany (0.60 m.).....2.80 "

According to the experience on narrow-gauge roads in different countries, the average cost of the substructure stands about in the following proportions :

Gauge	1 m.	0.75 m.	1.60 m.
Ratio	1	0.92–0.90	0.88–0.80

(*b*) *Savings in Superstructure.*—The smaller gauge admits of a lighter superstructure on account of the use of rolling stock with less pressure per axle. The ensuing savings in the weight of rails and angle bars in wooden or iron ties or sleepers, in the amount of ballast, and, finally, in the number and length of yard side tracks, may be very considerable.

While on standard-gauge local railroads the weight of rail per running meter varies between 23 and 31 kg., it is—

With a gauge of	1 m.	0.75 m.	0.60 m.
Weight in kilograms per meter	18.0–26.0*	15.0–18.0†	9.0–15.0‡
Bottom width of road-bed (wooden ties) per meter	2.2–2.4	1.75–2.0	1.6–1.7
Thickness of same in meters	0.30	0.25	0.20

With iron ties the thickness of the ballast is still less and decreases down to 0.15 m. Wooden ties have lengths of 1.8, 1.5 and 1.3 m., an upper width of 14, 13 and 12 cm. respectively, and a thickness of 14 and 16 cm. The distance between centers of tracks at the stations is, according to the width of rolling stock, 3.5 to 3.75 m. with 1-m. gauge; 3.30 to 3.50 m. with 0.76 or 0.75 m. gauges; and 3 to 3.20 m. with a 0.69-m. gauge. The clearance between passing vehicles is generally made 0.70 to 0.80 m.

For the superstructure the following ratios may be therefore assumed as an average :

Gauge	1 m.	0.75 m.	0.60 m.
Ratio	1	0.8–0.7	0.6–0.5

	Weight of rail per meter.
* In Austria-Hungary (1-m. gauge)	17.8–23 kgr.
† In " " (0.76-m. ")	17.8–23 "
" Bosnia and the Herzegovina (0.76-m. gauge)	9.8–17.9 "
" Bosnia and the Herzegovina on rack railroads (0.76-m. gauge)	21.8 "
Saxon narrow-gauge roads (0.75-m. gauge)	15.5 "
Waldenburg railroad, Switzerland (0.75-m. gauge)	15.1 "
‡ Décauville railroads, France (0.60-m. gauge)	9.55–15 "
Scandinavian railroads (0.60-m. gauge)	9.9 "

TABLE "A."

Principal Dimensions of Recent Locomotives in Operation on Narrow-Gauge Railroads with Gauges of 1.00, 0.75 or 0.76 and 0.6 m.

No.	Railroad.	Description.	Gauge.	Smallest admissible radius.	Steam pressure in atmospheres.	Grate area.	Total heating surface.	Diameter of cylinder.	Stroke of piston.	Diameter of coupled wheels.	Weight when in service, in tons.	Average drawing capacity in kilograms.	Notes.
			Meters.			Square Meters.		Meters.					
1....	S. Cristobal-Tucuman (The Argentine)	Tender-Locomotive, 3 axles coupled, weight empty, 13.6 tons (Cie. de Fives-Lille)	1.0	..	..	0.61	29.80	0.270	0.380	0.809	18.0	....	On exhibition at the Paris Exposition, 1889.
2....	Belgian Vicinal Railroads	Tender Locomotive, 3 axles coupled, weight empty, 18.5 tons (La Métallurgique)	1.0	..	..	0.77	34.30	0.350	0.360	0.832	22.8	....	*Vide* Organ f. d. Fortschr. d. E. Bw., 1891. Uebersicht der in Paris ausgestellten Loc. H. v. Littrow Stahl u. Eisen, 1892. Ueber Feldeisenbahnen, E. A. Ziffer.
3....	do	Tender-Locomotive, 3 axles coupled, weight empty, 15 tons (E. & J. Halot, Brussels)	1.0	..	..	0.72	30.80	0.280	0.360	0.820	18.0	....	
4....	Innsbruck-Hall (Tyrol)	Tender-Locomotive, 2 axles coupled (Krauss & Co. Munich)	1.0	..	15	0.29	12.84	0.180	0.300	0.750	7.8	970	Information from the Locomotive Works of Krauss & Co., Munich and Linz.
5....	do	" " " "	1.0	..	15	0.35	18.26	0.225	0.300	0.750	10.6	1 060	
6....	Jura-Simplon (Switzerland)	Tender-Locomotive for adhesion and rack railroad; 3 axles coupled, of which the central one is rack driving axle. Weight empty, 16.8 tons. (Winterthur, Switzerland)	1.0	..	15	0.98	54.7	0.330	0.480	{ 0.796 / T 0.806 }	21.4	....	
7....	Appenzell Tramcar Railway (Switzerland)	Combined rack and adhesion engine, 2 coupled axles and rack working gear, tender and one "Bissel" axle (Syst. Klose). Weight empty, 26 tons. (Winterthur Mach. Co.)	1.0	30	12	1.40	94.0	0.360	0.400	{ * 0.800 / ** 0.860 }	32.5	....	Monographie d'un chemin de fer routier à voie de 1 m. à adhérence et à crémaillère, J. Martin et L. Marad. Paris, 1891. Nouvelles Annales de la Constr. Décembre, 1891. * Adhésion } Mechanism. ** Rack } Mechanism.
8....	Salzkammergut and Styrian State Railways	Tender-Locomotive, 2 axles coupled. Weight empty, 9.5 tons. (Krauss & Co.)	0.76	..	12	0.43	23.48	0.225	0.350	0.75	12.0	1 400	Diameter of Tender Wheel, 0.555 m. Information from Krauss & Co.
9....	Salzkammergut, Steyrthal and Mori-Arco-Riva Railways	Tender-Locomotive, with combination pivot truck; 3 axles coupled, of which the near axle allows a lateral motion of 25 mm. each way. Adhesion weight, 18 tons. (Krauss & Co.)	0.76	30	12	0.8-1.0	43-50	0.290	0.400	{ 0.550 / T 0.800 }	22.7-24	2 500	Trial runs made with a maximum speed of 35 km. per hour
10....	Bosna Railroad	Curve Locomotive, 3 axles coupled, which are movable radially, and one tender-axle (Syst. Klose). Adhesion weight, 20 tons	0.76	30	12	0.90	58.82	0.290	0.450	0.900	25.0	2 520	Glaser's Annalen, 1888: Trial runs with 50 km. speed.
11....	do	Duplex-Locomotive (Syst. Fairlie). Weight empty, 19.2 tons. (Krauss & Co.)	0.76	30	12	1.0*	58.4	0.240	0.300	T 0.750	24.2*	2 430	Construction of two coupled locomotives, touching with their fireboxes; the two engines can be used separately. * Weight, empty and in service, grate and heating surface given for both engines.
12....	Herzegowinian Railroad, Maximum Grade 6 %	Combination Rack Railroad Locomotive (Syst. Abt). (Florisdorf Locomotive Works)	0.76	30	12	1.20	70.00	{ * 0.310 / ** 0.300 }	{ * 0.450 / ** 0.360 }	{ * 0.800 / ** 0.688 }	31.0	{ * 4 000 / ** 2 800 }	* Adhesion } Mechanism. ** Rack } Mechanism.
13....	Saxon Narrow-Gauge Railroads	Tender-Locomotive, 3 axles coupled. Weight empty, 12.45 tons. (Chemnitz Mach. Co.)	0.76	30	12	0.66	29.27	0.240	0.380	0.750	16.0	2 100	*Vide* Secondary Railways of Saxony. Berlin.
14 ...	do	Tender-Locomotive, with 2 boilers and 4 cylinders, twice 2 coupled axles and double furnace. Weight empty, 22.3 tons. (Syst. Fairlie.) (Glawthorn, Newcastle-upon-Tyne)	0.76	30	10	1.16	57.78	0.216	0.355	0.813	28.0	2 420	do
15 ...	Décauville Railroad (France)	Locomotive with 2 coupled axles and a tender with 2 axles. Weight empty, 5 tons. (Syst. Décauville)	0.60	15	9	0.29	8.72	0.150	0.300	0.60	6.25	722	*Vide* Const. et exploitation des chemins de fer à voie de 0.6 m. R. Tartary, Paris, 1891.
16 ...	do	Locomotive with 2 coupled axles and a tender with 2 axles. Weight empty, 5 tons. (Syst. Decauville)	0.60	20	9	0.30	15.0	0.210	0.300	0.70	7.50	1 020	*Vide* Const. et exploitation des chemins de fer à voie de 0.6 m. R. Tartary Paris, 1891.
17....	Paris Exposition and French Military Railways	Compound Tender-Locomotive, all 4 axles coupled. Weight empty, 4.5 tons. (Syst. Mallett)	0.60	..	12	0.42	22.3	{ V 0.170 / H 0.225 }	0.255	0.60	12.0	2 155	A. Mallet: Développement de l'application du système compound aux machines locomotives. Paris, 1890.
18....	do	Compound Tender-Locomotive, 2 pairs of coupled axles. Weight, empty, 9 tons	0.60	20	12	0.50	22.3	{ V 0.187 / H 0.280 }	0.300	0.60	12.0	1 800	Schweiz. Banzeitung, 1890.
19 ...	do	Duplex Tender-Locomotive, 2 bogies and 1 furnace. Weight empty, 10.5 tons. (Syst. Péchot-Burdon)	0.60	20	12	0.48	25.6	0.175	0.240	0.65	13.0	1 900	
20....	Décauville Railroad (France)	Combination Rack Railroad Locomotive. Weight empty, 13 tons. Etabliesement Décauville)	0.60	{ 20 * / 80** }	12	....	27.0	0.250	0.360	0.72	16.0	....	Information from the Décauville Company. * 20 m. Adhesion } Railroads. ** 80 m. Rack } Railroads. The engine may reach a weight of 21 tons. The trains on the railroads of the Departments Loiret and Calvados, on the Royan tramcar line and on the Escoublac-la-Bôle Pornichet Railroad, run with a speed of 25 to 30 km. per hour.

* The Scandinavian Local Railways, 0.6 m. gauge, use compound locomotives with four cylinders and eight driving wheels which are able to draw a 40-ton train at a speed of 24 km. per hour on gradients of 2.86%, and which pass curves of 20 m. radius.
Noticeable are the Legrand Compound Tender Locomotives for 0.6-m gauge, weight in service, 5.5 tons, 2 coupled axles, which can be also used for 1-m. gauge. To do this, the axles are taken out, the wheels are put outside of the frame and the crank pins are keyed on to them; the journal boxes and all the other mechanism remain unchanged.
There is further worth mentioning the Corpet and Décauville Tender-Locomotive, 0.6-m. gauge, for industrial and agricultural purposes. *Vide* "La Locomotive à voie étroite à l'Exposition de 1889," Génie civil, 1890, "Ueber Feldeisenbahnen," E. A. Ziffer, Stahl und Eisen, 1892.

(*c*) *Savings in Buildings.*—These savings can become very large if a railroad limits itself to provisional and absolutely necessary structures, which may be done especially on roads with smaller gauge accommodating a limited traffic. But savings in the depots are possible in every case.

II. *Saving in Equipment.*—The smaller the gauge, the less becomes the weight of the rolling stock, without necessarily diminishing its stability or effectiveness in equal proportion. Unquestionably, the cost of the equipment, built lighter for a lighter traffic, diminishes also with the gauge, even under the same requirements concerning carrying capacity and appliances of safety and precaution (brakes, drawing gear, buffers, etc.).

Table "A" of "Principal Dimensions of Locomotives," shows that the engines for a smaller gauge (0.86 or 0.75 m.) have been constructed with a larger grate area and a greater drawing capacity than those for 1-m. gauge; further, that engines for 0.6-m. gauge are capable of meeting very stringent demands, especially as to drawing capacity, adhesion, weight and flexibility in passing sharp curves. Combined rack railroad locomotives for a 0.76-m. gauge have also been long in operation without giving any trouble or being less safe.*

The construction of modern locomotives is certainly suitable to facilitate the building of railroads at a small outlay and to guarantee the earning capacity of lines, very doubtful at a greater cost. We find, also, that all hindrances to narrow gauge have been removed as to the effectiveness of locomotives.†

‡Table "B" of "Covered and Open Freight Cars" shows that cars with a loading capacity of 10 tons can be built, not only for 1-m. gauge, but also for smaller gauges, in which case the dead weight per ton of capacity, available area and volume of cars is lessened.

§Table "C" gives the main dimensions of passenger cars, which show also a more favorable proportion between gauge and width of cars. The cars for the Salzkammergut and the Styrian Local Railroads (0.76-m gauge) are 2.2 m. wide, those of Décauville (0.60 m.) are 1.7 m., that is, almost three times as wide as the gauge, and have been in unobjectionable use for an extended period. The cars of the Bosna

* In the Décauville shops the writer saw a combined (adhesion and rack) locomotive for 0.60 m. gauge, the dimensions of which are also contained in "Table A."

† "Ueber die Secundärbahnen in Frankreich," E. A. Ziffer, Zeitschr. f. Eisenb. u. Dampfschiffah t, Mai. 1891. Zeitschr. f. Transportw. u. Strassenbau, No. 24, bis 30, 1892.

‡ See pp. 18–20.

§ See pp. 22, 23.

TABLE B.

PRINCIPAL DIMENSIONS, WEIGHT, CAPACITY, ETC., OF RECENT FREIGHT CARS, IN OPERATION ON NARROW-GAUGE RAILROADS WITH GAUGES OF 1, 0.75 OR 0.76 AND 0.6 M.

Number.	Railroad.	Gauge in Meters.	Number of Axles. Distance c. c. in Meters.	Body of Car.			Own Weight.	Capacity.	Ratio of Own Weight to Capacity.	Dead Weight per Ton of Capacity in Kilograms.			Available Area for Loading.	Available Volume for Loading.	Notes.
				Length.	Width.	Height Above Rail.				Box.	Gondola.	Platform.			
				Meters.			Tons.			Average Car.			Sq. M.	Cu.M	
1..	Belgian Vicinal Rys	1.0	.....	.....	.....	.....	.....	10.0	.....	.....	400	.....	.....	.....	Bull. de la Comm. Internat. du Cong. des chems de fer, Mars, 1892.
2..	" do	1.0	.....	.....	.....	.....	.....	5.0	.....	.....	540	.....	.....	.....	
3..	Économiques du Nord (France)	1.0	.....	.....	.....	.....	.....	10.0	.....	445	390	370	.....	.....	
4..	Sud de la France (Var et littoral).....	1.0	.....	.....	.....	.....	.....	10.0	.....	550	450	350	.....	.....	
5..	Circum-Etna (Sicily).....	1.0	.....	.....	.....	.....	.....	7.5	.....	400	375	312	.....	.....	
6..	Skagens Railway (Denmark).....	1.0	2 / 3.6	4 0	1.80	1.9	2.04 / 2.23	5.0	1:2.45 / 1:2.24	408 / 446	.....	.....	7.2	13.68	"Die Skagensbahn" Kuhrt. Z f. Loc. u. Strass.Bw.,1891.
7..	do.....	1.0	2 / 2.5	3.97	1.84	0.7	2.20	5.0	1:2.27	.....	440	.....	7.2	5.04	
8.	Filder Ry. (Stuttgart-Degerloch).....	1.0	2 / 2.8	6.07	2.37	.....	3.23	8.0	1.2.47	.....	.....	404	.....	.....	Z. f. Loc. u. Strass. Bw., 1886.
9..	County Ry, Flensburg-Kappeln (Schleswig)....	1.0	2 / 2.7	6.05	2.15	2.91	5.37	5.0	1:0.93	1074	.....	.....	13.0	27.3	Die schmalspur. Kreiseisenb. Flensburg-Kappeln. Kuhrt. Z f. L. u. Str. Bw ,1886.
10..	do.....	1.0	2 / 2.3	4.3	2.15	2.89	3.31	5.0	1.1.51	662	552	.....	9.24	20.3	
11..	do.....	1.0	2 / 2.3	4.5	2.15	1.55	2.76	5.0	1:1.81	.....	.....	500	9.67	7.73	
12..	do.....	1.0	2 / 2.3	4.5	2.15	.....	2.50	5.0	1:2	.....	.....	.....	9.67	.....	

13..	Eichstadt-Stadt. Eichstadt (Bavaria).....	1.0	.....	5.4	2.5	2.95	3.4 4.0	7.5	1:2.21 1:1.87	405 533	.....	.....	13.5	29.7	Z. f. Loc. u. Strass. Bw., 1886.
14..	do	1.0	.....	5.4	2.5	1.94	3.2	7.5	1:2.34	.....	426	.....	13.5	16.2	
15..	Felda Ry. (Sachsen-Weimar).....	1.0	2 2.3	4.45	2.1	2.9	2.5	5.0	1:2	.....	.....	500	9.34	20.08	
16..	do.....	1.0	2 2.7	5.93	2.15	1 36	3.2 2.3	7.5	1:2.58 1:2.34	.....	387 426	.....	12.75	7.65	Z. f. Loc u. Strass. Bw., 1885.
17..	Innsbruck-Hall (Tyrol).....	1.0	2 1 8	5.0	2.1	3.0	2.85	5.0	1:1.75	570	.....	.....	10.5	23.1	
18..	Lugano Lake Narrow-Gauge Ry. (Switzerland)	0.8	4 5 0	7.5	.....	.....	4.5	10.0	1:2.22	.....	.....	.....	.....	.....	Z. f. Loc. u. Strass. Bw., 1886.
19..	I. R Bosna. and Bosnian-Herzegowinian State Ry	0.76	2 2.7	5.00 4.50	1.80	2.27	3.0 3.2	6.0	1:2 1:1.87	378 533	.....	.....	9.0 8.1	.....	The freight cars with two axles have room for 20 soldiers; those with three axles for 30 soldiers or four horses; all axles are radially movable (Syst. Klose).
20..	do.....	0.76	3 5.0	7.30 6.80	1.80	2.27	5.1 5.6	10.0	1:1.96 1:1.78	510 560	.....	.....	13.14 8.84	.....	
21..	do.....	0.76	2 2.7	5.0	1.90	0.9	2.4 2.6	6.0	1:2.5 1:2.30	.....	400 433	.....	9.5	8.55	
22..	do.....	0.76	3 5.0	7.3	1.90	1.0	4.3 4.8	10.0	1:2.32 1:2.08	.....	430 480	.....	13.87	13.87	
23..	do.....	0.76	2 2.7	5.0	1.90	0.6	2 4 2.6	6.0	1:2.50 1:2.30	.....	.....	400 433	9.50	5.70	
24..	Mori-Riva-Arco (Tyrol).....	0.76	2 3.7	6.0	1.85	2.87	3.5	5.0	1:1.43	700	.....	.....	11.10	24.42	
25..	do.....	0.76	2 3.7	6.0	2.0	1.0	2.8	5.0	1:1.78	.....	560	.....	12.0	12.0	Coal cars with brakes.
26..	do.....	0.76	2 3.7	6.0	2.0	.....	2.7	5.0	1:1.85	.....	.....	540	12.0	2.93	
27..	Salzkammergut Ry. and Styrian State Rys	0.76	2 3.7	6.3	1.97	2.89	3.45	5.0	1:1.44	690	.....	.....	12.41	27.30	Box cars with brakes.
28..	do.....	0.76	2 3.7	6 3	2.0	1.61	3.05	5.0	1:1.64	.....	.....	610	12.6	12.6	With brakes.
29..	Steyr Valley Ry. (Upper Austria).....	0.76	2 3.8	6.0	2.0	2.85	3.8	6.0	1:1.57	633	.....	.....	8.82	18.0	
30..	do.....	0.76	2 3.8	6.0	1.86	1.57	2.9	6.0	1:2.07	.....	483	.....	11.10	10.0	
31..	do.....	0.76	2 3.8	6.0	1.86	0.975	2.7	6.0	1:2.20	.....	.....	450	11.10	2.5	
32..	Bari-Barletta (Italy).....	0.75	.....	.....	.....	.....	.....	6.0	.....	450	391	408	.....	.....	Bull. de la Comm. Internat. du Cong. d. ch. d. fer, Mars, 1892.
33..	Saxon Narrow-Gauge Rys...	0.75	2 2.7	4.1	1.7	2.57	1.925 2.100	5.0	1:1.92	385 420	.....	.....	6.97	13.9	"Die neuesten Schm. spurb. in Sachs." Dickmann, Z. f. L. u. Str. Bw. 1885 u. 1887, Civil Ingenieur, 1885.
34..	do.....	0.75	2 3.8	5.8	1.6	1.55	2.023 2.21	5.0	1:2 46 1:2.27	.....	405 440	.....	9.28	4.176	
35..	do.....	0.75	2	4.1	1.75	2.5	2.10	5.0	1:2.38	.....	.....	420	7.17	7.6	

TABLE B—(*Continued*).

Number.	Railroad.	Gauge in Meters.	Number of Axles. Distance c. c. in Meters.	Body of Car. Length.	Body of Car. Width.	Body of Car. Height Above Rail.	Own Weight.	Capacity.	Ratio of Own Weight to Capacity.	Dead Weight per Ton of Capacity in Kilograms. Box.	Dead Weight per Ton of Capacity in Kilograms. Gondola.	Dead Weight per Ton of Capacity in Kilograms. Platform.	Available Area for Loading.	Available Volume for Loading.	Notes.
				Meters.			Tons.			Average Car.			M^2	M^3	
36.	Mannsfeld Narrow-Gauge Rys. (Prussia)	0.75	2	5.05	1.65	.....	2.80 3.0	5.0	1:1.78 1:1.66	.....	560 600	.....	8.33	9.16	Z. f. d. ges. L. u. Str. Bw., 1885.
37..	do	0.75	2	4.56	1.0	.....	2.25 2.45	6.0	1:2.66 1:2.45	.....	.....	375 408	4.56	2.28	
38..	Waldenburg Ry. (Switzerland)	0.75	2 2.0	4.03	1.75	2.86	2.480	5.0	1:2.02	496	.....	.....	7.05	15.50	"Die Waldenburger Bahn" Brodbeck Z. f. d. ges. L. u. Str.Bw.,1882.
39..	do	0.75	.. ....	4.03	1.75	2.8	2.05	5.0	1:2.44	401	.....	.....	7.05	15.50	
40..	do	0.75	.....	4 0	1.75	0.45	1.6	5.0	1:3.12	.....	302	.....	7.0	3.15	Constr.et exploit.des Ch. de fer à voie de 0.6 m. Tartary, Paris, 1891.
41..	Décauville Ry. (France)	0.6	2 1.5	3.5	1.62	1.70	0.9	3.0	1:3.33	300	.....	.....	5.67	10.94	
42..	do	0.6	2 1.5	4.0	1.70	1.89	1.2	5.0	1:4.16	240	.....	.....	6.80	13.60	Capacity not limited to 10 tons; there are cars with single loads of 18,36 and 48 tons, which weigh only 200 kg. per ton, capacity, *i. e.*, 20% of the load.
43..	do	0.6	4 3.5	6.0	1.70	2.41	2.7	10.0	1:3.70	270	.....	.....	10.2	19.38	
44..	do	0.6	4 3.5	6.0	1.70	2.41	3.7	10.0	1:2.70	370	.....	.....	10.2	19.38	
45..	do	0.6	4 3.6	6.0	1.70	1.25	2.7	10.0	1:3.70	.....	270	.....	10.2	7.14	

The freight cars of the Scandinavian railways of 0.6-m. gauge have a capacity of 5 tons; weight, 1 to 1.3 tons; distance c. c. axles, 2 m.; length of car body, 4 m.

A decree of the French Secretary of the Department of Public Works fixes the maximum clearance profile as follows:

1-m. gauge: Width of car, 2.8 m.; Height, 2.8 m.
0.75 m. " " " 2.5 m.; " 2.7 m.
0.6-m. " " " 2.2 m.; " 1.8 m.

In the columns, "Own Weight," and "Ratio of Own Weight to Capacity," the figures above the lines refer to cars without brakes, and the figures below the lines to such with brakes.

Railroad (Coupé system) give a clear width of 1.8 m., so as to admit of a recumbent position of the passengers. To facilitate the passing of curves, movable axles or trucks are, of course, used on narrow-gauge roads; the latter have been adopted for the Décauville cars, which may be considered as examples to be followed. Special mention should be made of the combined cars, length over all 9.8 m., inside length of box 5.95 m.; then those with an outside width of box of 1.7 m., and an inside width of 1.65 m., weight 4.7 tons, capacity four horses, four head of cattle or 24 men; finally, the covered box cars, volume 20 cu. m., capacity 10 tons, with floors so low that inclined platforms are dispensable for loading and unloading.

In comparing the dimensions of rolling stock given in the above three tables, their mode of construction has to be taken into consideration. The dead weights of cars depend also on the material, for which the writer has no data.

Total Savings in the Construction of Narrow-Gauge Roads.—Considering the savings in narrow-gauge roads in their entirety, the estimates of eminent engineers for certain railroads in different countries, for various gauges, always taking the greatest admissible grades and smallest radii, result in saving, according to the chosen gauge and the locality, 30 to 70% against standard gauge. With the difficulties of the locality, the saving by the use of narrow gauge increases. But these data can give directions only; special estimates must be made for each separate case, and the difference of cost has to be calculated for the different gauges.

III. *Savings in Operation.*—The working expenses comprise:

(*a.*) General administration.

(*b.*) Maintenance and inspection of roadbed.

(*c.*) Station and yard service.

(*d.*) Train and shop service.

Strictly speaking, the cost of the general administration and partly of the station and yard service is independent of the gauge; but the saving in maintaining and inspecting the roadbed is quite noticeable, as there is less substructure work, especially less and not so important masonry work, a lighter construction of superstructure and lower speed of trains. There are savings by the limited extent of buildings, and in the train and shop service, due to the less wear of rolling stock by its smaller dead load and more simple construction, and also to shorter trains and to the easier handling of them in the stations.

TABLE C.

PRINCIPAL DIMENSIONS AND WEIGHTS OF RECENT PASSENGER CARS IN OPERATION ON NARROW-GAUGE RAILROADS, WITH GAUGES OF 1, 0.75 or 0.76 AND 0.60 M.

Number.	Railroad.	Gauge in Meters.	Number of Axles. / Distance c. c. Axles in Meters.	Class of Compartments.	Body of Car. Meters. Length.	Width.	Height.	Ratio of Gauge to Width of Car Body.	Seats. Number.	Length. Per Passenger in M.	Width. Per Passenger in M.	Own Weight in Tons.	Dead Weight per Seat in Kg.	System.	Notes.
1..	Belgian Vicinal Railways	1.0	.....	II	.....	2.20	....	2.20	.....	0.50	0.42	.....	114	.....	Bull. de la Comm. Intern. du Congr. des chemins de fer, Mars, 1892.
2..	Chem. de fer écon. du (Nord) France	1.0	.....	II	.....	1.90	....	1.90	.....	0.45	0.45	.....	132	.....	
3..	Chem. de fer du Sud de la France (Centr. Var. et Littoral)	1.0	.....	I	.....	2.55	....	2.55	.....	0.51	0.50	.....	239	.....	
4..	Circum-Etna (Sicily)	1.0	.....	III	.....	2.32	....	2.32	.....	0.42	0.27	.....	132	.....	
5..	Skagens Ry. (Denmark)	1.0	.....	II & III	6.0	2.10	2.0	2.10	....	.....	.....	3.9	.....	Coupé car.	Z. f. d. ges. L. u. Str. Bw., 1891.
6..	Filder Ry. (Stuttgart-Degerloch)	1.0	2 / 4	.....	7.73	2.47	2.15	2.47	48	.....	.....	5.63	118	Intercom c.	Z. f. d. ges. L. u. Str. Bw., 1886.
7..	do	1.0	2 / 2.3	.....	5.55	2.15	2.30	2.15	24	.....	.....	4.24	176	do	
8..	County Ry. Flensburg-Kappeln (Schleswig)	1.0	2 / 2.7	II & III	5.97	2.20	2.18	2.20	24	.....	.....	5.30	220	do	Z. f. d. ges. L. & Str. Bw., 1886.
9..	Eichstadt-Stadt. Eichstadt (Bavaria)	1.0	.....	.....	5.77	2.5	2.95	2.5	32	.....	.....	5.00	156	.....	Standing room for 14 to 16 passengers.
10..	Felda Ry (Sachsen-Weimar)	1.0	2 / 2.3	II & III	5.44	2.1	2.91	2.1	24	.....	.....	4.30	179	Intercom c.	Transverse seats. Z. f. d. ges. L. u. Str. Bw., 1886.
11..	Innsbruck-Hall (Tyrol)	1.0	2 / 1.8	.....	3.6	2.1	1.88	2.1	16	0.55	0.45	2 55	153	do	Longitudinal seats.
12..	Lugano Lake Narrow-Gauge Ry. (Switzerland)	0.8	.....	I & III	.....	....	....	....	24 / 40	.....	.....	5.8 / 5.2	242 / 130	.....	Z. f. d. ges. L. u. Str. Bw. 1886.

13..	I. R. Bosna and Bosnian-Herzegowinian State Ry....	0.76	2 / 2.7	I & II	4.89	1.63	1.87	2.14	14	1.Cl. 0.9 / 2.Cl. 0.65	0.60	2.3	164	Coupé.	Transv'se seats.	
14..	do.....	0.76	3 / 5	I & II	7.24	1.79	2.40	2.37	22	1.Cl. 0.9 / 2.Cl. 0.65	0.60	7.0	318	do	do	
15..	do.....	0.76	2 / 2.7	III	4.36	1.78	2.05	2.36	15	0.45	0.45	3.6	240	do	do	Cars run very smoothly, even at a speed of 40 km. Axles are radially movable. System, Klose.
16..	do.....	0.76	3 / 5	III	6.74	1.79	2.40	2.37	24	0.45	0.45	6.9	287	do	do	
17..	do.....	0.76	2 / 2.7	IV	4.86	1.78	2.05	2.36	16	0.40	0.42	3.2	200	do	do	
18..	do.....	0.76	3 / 5	IV	7.24	1.79	2.15	2.37	30	0.40	0.42	6.1	200	do	do	
19..	Mori-Riva-Arco (Tyrol)	0.76	2 / 3.7	I	5.64	2.1	2.87	2.76	16	0.68	0.50	4.5	281	Intercom.	do	
20..	" "	0.76	2 / 3.7	I & III	5.64	2.1	2.87	2.76	24	1.C.0.50 / 3.C.0.475	0.50 / 0.475	4.15	173	do	do	
21..	Salzkammergut Ry. and Styrian State Rys.....	0.76	2 / 3.7	I	5.54	2.2	2.87	2.76	14	0.68	0.5	4.5	321	do	do	
22..	Salzkammergut Ry. and Styrian State Rys.....	0.76	2 / 3.7	II	5.54	2.2	2.87	2.89	21	0.49	0.5	4.1	195	do	do	Data of the car works of J. Weitzer, Graz.
23..	do.....	0.76	2 / 3.7	II & III	5.54	2.2	2.87	2.89	24	0.47	0.45	4.1	171	do	do	
24..	do.....	0.76	2 / 3.7	III	5.54	2.2	2.87	2.89	24	0.475	0.475	4.5	168	do	do	
25..	Steyr Valley Ry. (Upper Austria.....	0.76	2 / 3.8	III	5.00	1.8	2.85	2.38	20	0.485	0.50	3.75	187	do	Longit. seats.	
26..	Bari-Barletta (Italy).....	0.75	.....	III	.....	1.9	....	2.63	.....	0.38	0.27	.....	96	.....	Bull. de la Comm. Intern. du Congr. de chem. de fer, Mars, 1892.	
27..	Saxon Narrow-Gauge Rys....	0.75	2 / 3.3	III	5.8	1.62	2.0	2.16	16	.....	.....	2.45	153	.....	Standing room for 6 pass., brake; sliding axles.	
28..	" "	0.75	4	II & III	10-62	1.62	2.0	2.16	33	.....	.....	4.75	143	.....	Sliding axles.	
29..	Mannsfeld Narrow-Gauge Rys. (Prussia).....	0.75	2 / 5	III	5.7	1.65	2.65	2.16	.....	.....	.....	3.6	.....	.....	Movable axles, Longit seats.	Z. f d. ges. L. u. Str. Bw., 1885.
30..	do.....	0.75	4 / 5.3	.....	6.1	2.0	3.50	2.66	60	.....	.....	4.4	73	.....	For workingmen trains, with roof seats, longt. seats and bogie trucks.	
31..	Waldenburg Ry. (Switzerland)	0.75	2 / 2.35	II & III	5.5	1.75	2.84	2.33	21	.....	.....	3.1	147	.....	Standing room for 6 pass., transv'se seats.	Z f d. ges. L. u. Str. Bw., 1885.
32..	" " ..	0.75	2 / 2.35	II & III	5.5	1.75	2.84	2.33	18	.....	.....	2.5	138	.....	Standing room for 10 pass., lng. seats.	
33..	Décauville Ry. (France).....	0.60	2 / 1.4	I & II	3.8	1.70	2.33	2.83	12.16	.....	.....	1.05-1.35	85	.....	Constr. et exploit des chems. de fer à voie de 0.6 m. Tartary, Paris, 1891.	
34..	" "	0.60	2 / 1.4	III	3.6	1.70	2.33	2.83	16	.....	.....	1.35	85	.....		
35.	" "	0.60	4 / 6.5	III	9.0	1.70	2.41	2.83	56	....	.....	4.5-6 5	80-116*	.....	*Dead w't can be reduced to 70 kg. on summer cars.	

All these savings in working expenses can be proved only by elaborating comparative studies on the systems of operation for different narrow gauges. Otherwise, the given differences can be regarded as only approximately correct.*

Disadvantages of Narrow-Gauge Roads in Detail.—The supposed disadvantages are :

I. Limited traffic, small efficiency and little usefulness for military transports. These objections are contradicted by actual experience. The writer will cite the following widely known examples :

1st. The single-track road, gauge 1 ft. 11½ ins. (0.597 m.), from Festiniog to Port Madoc, in North Wales, built as a horse-car line in 1832, gradually rebuilt and operated by locomotives since 1864. It is 23 km. long and has 12 branches with the same gauge with a total length of 22 km., leading to the slate quarries of Galles. The original capital, 40 000 francs per kilometer, has been raised to 165 000 francs per kilometer by a series of transformations, and consists of stocks exclusively. The weight of rail has increased from 8 kg. per meter in 1832, successively to 15 kg. in 1847 and to 24 kg. in 1871. The maximum grade is 1.25%, the curves with radii of ordinarily 120 m. go down to radii of 35 m., used without tangents between reversed curves.

Traffic has continually increased since 1865 ; in the beginning, the number of passengers was 23 000 per annum ; while in 1888, 142 000 persons and 113 000 tons of freight were carried, and this during the day only (no trains run on Sunday). There are 12 trains in each direction daily, of which six are passenger trains ; the trains number often up to 150 cars, with an aggregate length of 360 to 400 m. The annual gross receipts per kilometer reached the sum of 29 000

* Die gemischte Spur. Jahrb. d. sächs. Ing. u. Arch. Ver., Köpke, 1883. Frankreich's Local u. Schmalspurb., W. v. Nördling. Zeitschr. f. d. ges. Local u. Strassenbahnw., 1886.

Ueber Schmalspurbahnen f. Pers. u. Güterverkehr. Mittheil. über derartige Bahnen in North Wales, spec. über die Festiniog Bahn, R. Koch, Z. f. d. ges. L. u. Str. Bw., 1881.

Betriebsresultate d. Schmalspurb., Bröhlthal, Felda. u. Waldenburgerbahn. Z. f. d. ges. L. u. Str. Bw., 1883-1891.

Die Zuider Dampftramway, W. Hostmann. Z. f. d. ges. Loc. u. Str. Bw., 1882.

Ueber schmalspurige Industrie Bahnen, Hostmann. Z. f. d. ges. Loc. u. Str. Bw. 1882.

Die Brünigbahn, O. Zschokke u. G. Ott, Z. f. d. ges. L. u. Str. Bw., 1882-83 u. 1886.

Ueber Schmalspurb., A. Birk. Z. d. öst. Ing. u. Arch. V., 1885.

Bau u. Betrieb d. Schmalspurb., Hostmann, Wiesbaden, 1881.

Vergleich. Betracht. über Bau u. Betriebsergebnisse normal u. schmalspuriger Secundärb. O. Schröter. Z. f. d. ges. L. u. Str. Bw., 1882.

Neuere Fortschritte d. Schmalspurb , A. Birk ; Z. d. Ver deutcher Eisenbahnverw., Nos. 96-98, 1891.

francs, of which 8 000 francs are due to the passenger traffic.* The traffic is consequently four times as large as that of the Algerian railroads, and the yearly net receipts amount to nearly 34 000 francs, which income would authorize the French government to compel the Algerian roads to lay a second standard-gauge track.

2d. The Illigori Darjeeling Railway, in British India, 2-ft. (0.61-m.) gauge, on the road from Calcutta to the first plateau of the Himalaya, at an altitude of 2 000 m. above sea-level, is laid mostly along the highways with average grades of 2.5%, a maximum grade of 3.5% and curves with radii down to 21 m. Weight of rail, 21 kg. per meter. Cost, 78 000 francs per kilometer. In 1888, 42 800 passengers and 24 700 tons of freight were carried at gross receipts of 17 940 francs per kilometer. The running expenses were 54% of the receipts.

3d. The railroad from Antwerp to Ghent, in Belgium, gauge, 1.15 m., length, 50 km., built between 1844 and 1847, is operated similarly to trunk lines with through trains of 50 km. hourly speed. This road carried 500 000 passengers and 50 000 tons of freight in 1865; in 1887 the passengers numbered 1 089 838, and the receipts were 765 409 francs; 713 591 francs were received for baggage, express, and common freight. The expenses were 64.09% of the income.†

4th. The Paris Exposition Railroad on the Champ de Mars, in 1889, surnamed "Décauville Railroad," 3 km., 0.60-m. gauge, carried six and one-half millions of passengers within six months. This is double the rate of the Dépôt de la Bastille in Paris, which summed up only five and one-half millions in 12 months. Forty-two thousand five hundred trains were run, with a total weight of 1 781 018 tons, making 106 250 train-kilometers. Each train had a capacity of 400 travelers. The gross receipts per kilometer in six months were 550 000 francs; the operating expenses were 160 000 francs, or 30% of the receipts. The maximum grade was 2%; the smallest radius was 30 m. on the open road and 20 m. at the stations. This was, undoubtedly, the first time that such a record was made on a 0.60-m. gauge road with such primitive means, and we are used to such a showing on first-class standard-gauge roads only.‡

* Bau u. Betr. d. Schmalspurb., W. Hostmann, Wiesbaden, 1881.

Hostmann's Mittheil. über Lokalb. 1882. Ueb. d. Betriebsergebnisse, 1871–77.

† Dr. Röll's Encycl. d. ges. Eisenbw., I Band., 1890.

‡ "Das Eisenbahnw. auf der Weltausstellung in Paris," A. Birk, Z. d. V. deutscher Eisenbahnverw., No. 73, 1889.

"Die Pariser Ausstellungsbahn v. Décauville," A. Brunner, Z. d. V. Eisenbahnverw., No 6, 1890.

Le chemin de fer Décauville pendant l'Exposition de 1889, Corbeil, 1891.

5th. The Vicinal Railroad from Pithiviers to Toury, France, 31 267 km. long, of which 19.4 km. use the highways, has been built with a gauge of 0.6 m., maximum grades of 2.3% and 30 m. smallest radius, at an expense of 25 000 francs per kilometer. Six trains are run daily, with a maximum speed of 25 km. per hour.

6th. The Vicinal Railroad from Luc-sur-Mer to Dives, France, 29 km., built along the highways with a gauge of 0.6 m., has maximum grades of 3% and a smaller radius of 20 m. The cost was 35 000 francs per kilometer. Twenty-four trains are scheduled daily, with an hourly speed of 30 km. Each train seats 225 persons.

Considering the favorable results of the fore-mentioned French local roads, the General Council of the Departement de Calvados resolved, August, 1892, to adopt the 0.6-m. gauge also for the county system of secondary roads, comprising several hundred kilometers.

7th. The results of narrow-gauge roads in Hungary are contained in the following table:

Name of Railroad.	Gauge in meters.	Operated length in kilometers.	1890				
			Cost in florins per kilometer.	Gross receipts per kilometer in florins.	Total expenses in per cent. of gross receipts.	Net receipts in per cent. of cost of railroad.	Dividends of common stock, per cent.
Buda-Pesth-Szt. Lörinczer Railroad....	0.76	8.6	21 555	4 374	60.5	8.8	6.5
Gölnitz Valley Railroad.....	1.00	33.0	44 865	4 415	50.5	5.0	
Taracz Valley Railroad.....	0.75	32.8	19 750	472	58.5	1 0	
Marmaroser Railroad.....	0.75	40.3	22 446	2 425	35.5	9.9	4.5
Belisce-Kápolnaer Railroad.....	0 76	38.5	18 797	2 817	51.0	7 4	
Buda-Pesth Local Railroads.....	1.44	41.1	41 865	4 064	87.1	1.3	

At the end of the table the figures are given for the standard-gauge Buda-Pesth local roads. This line is operated under exactly the same conditions of traffic as the Buda-Pesth-Szt. Lörinczer Railroad, and furnishes a practical example showing how much more profitable, under the same conditions, a narrow-gauge road may be than one with standard gauge. The gross receipts are almost alike, but the operating expenses of the narrow-gauge road amount to 60.5%, and those of the standard-gauge road to 87.1%, of the gross receipts. The operation of the former is consequently more economical, though its length is 8.6

km. only, while the administration expenses of the latter road are distributed over 41.1 km.*

8th. The Agricultural Railroad on the Crown Estates Mezöhegyes in Hungary, 0.76-m. gauge, opened in 1889, is 34 km. long, has maximum grades of 5%, smallest radii of 60 m. Cost, 7 500 florins per kilometer.†

9th. The Bosna and the Bosnian-Herzegovinian Government Railroads. Gauge, 0.76 m. The former was built as a supply road during the occupation campaign of 1878; it was very imperfect technically, and of small efficiency of transportation. The original cost averaged 20 900 florins per kilometer, but it has been gradually transformed and lengthened.

At present the system of the Bosna Railroad‡ consists of—

(*a*) The Bosnian Brod-Doboj-Zenica Railroad, 189.7 km., the cost of which reached 49 200 florins per kilometer. The smallest radius is generally 50 m., with exceptional curves of 35 to 40 m. radius. The invested capital of 7 410 311 florins brought 4.21% interest in 1891 against 5.73% in 1890.

(*b*) The Zenica-Serajewo division of the Bosnian-Herzegovinian Government Railroad, 78.6 km., cost per kilometer 48 157 florins, smallest radius 275 m., steepest grade, 8 per cent. The invested capital is 3 902 034 florins and paid 3.31% in 1891, against 4.39% in 1890. On this line, and on the above-mentioned Bosnian Brod-Zenica Railroad, 254 669 passengers and 172 935 tons of baggage, express and ordinary freight, were carried. Each passenger averaged 77.1 km., and each ton of freight 102.07 km.; 27.16% of the receipts belong to the passenger traffic. The operating expenses were 55.6% of the receipts.

(*c*) The Vogoscá-Cjevljanovic mining road, 20.5 km. Minimum radius, 40 m., steepest grade, 0.2 per cent. Average cost per kilometer, 5 765 florins.

---

* "Die schmalspurigen Localb. in Ungarn." Z. d. V. d. Eisenbahnverw. No. 5, 73 u. 76, 1892.

† "Die landwirtschaftl. Industriebahn d. Mezöhegyeser Staatsgestü'sgüter." Z. d. V. d. Eisenbahnverw. No. 90, 1892.

‡ "Die Bosnabahn." W. v. Nördling, Z. f. d. ges. L. u. Str. Bw. 1883. "Die bosnischen Bahnen." E. v. Gutenberg, Oest. Eisenbahnz. Nos. 14 u. 15, 1886. "Die K. u. K. Bosnabahn," 1879–1889, Serajewo, 1889. "Die Bosnabahn, speciell ihre bauliche Anlage." Z. f. d. ges. L. u. Str. Bw. 1890, Dr. Röll's Encycl., II Band, 1890. Der Bau u. Betrieb der K. u. K. Bosnabahn u. d. Entwickl. d. bosn. Eisenbahn. A. Obermayer. Oest. Eisenbahnz. Nos. 52 u. 53, 1882. Ueber Bau u. Betrieb d. bosn.-herzeg. Staatsbahnen, bes. d. Zahnradbahn zw Serajewo u. Konjice, F. Pfeuffer. Z. d. oest. Ing. u. Arch. V. Nos. 22 u. 23, 1893. Bericht ü d. Studienr. in Bosnien, Mai, 1888. P. Kortz, Wochenschr, d. oest. Ing. u. Arch. V. Nos. 35 u. 38, 1888. Verordnungsbl. f. Eisenb. u. Schiffahrt No. 133, 19. Nov., 1892.

(*d*) The line Doboj-Sinnin-Han, 66.7 km., smallest radius 80 m., steepest grade 1%; cost per kilometer, 19 490 florins. The track is old steel rails, 14.2 kg. per meter, from the Tobuk-Zenica Railroad. In 1891, 74 841 passengers and 95 528 tons of baggage, express and ordinary freight were carried. Each traveler made on an average 29.8 km., and each ton of freight 44.55 km. The gross receipts are 135 584 florins, of which 22.65% are due to the passenger traffic. The operating expenses were 103.86% of the receipts against 65.29% in 1890.

(*e*) The division Metkovic-Mostar, 43.2 km., smallest radius 100 m., steepest grade, 3.33%; cost of construction per kilometer, 40 000 florins.

(*f*) The line Mostar-Ostrozac-Serajewo, 133.5 km. The Ivan Mountain is passed by the combined adhesion and Abt rack railroad system in a length of 15.14 km. On the mountain division the maximum grade is 6%, the smallest radius 125 m.; in the valley division the smallest radius is 80 m., and the maximum grade 1.5 per cent. The rails of the adhesion line are Vignol rails, weighing 17.9 kg., and those of the rack railroad weigh 21.8 kg. per meter. The division Mostar-Rama, 56 km., cost 50 000 florins per kilometer on an average, and the Rama-Serajewo division, 77.5 km., averaged 71 000 florins per kilometer.

This system, in its entirety, takes the place of a trunk line. There is an average of 3.3 trains per day with hourly speeds of 23 to 30 km. The number of trains in each direction can, however, be increased to 24. This alone refutes the supposed small efficiency of narrow-gauge roads for military purposes.

10th. The Saxon Narrow-Gauge Roads, 0.75-m. gauge, comprising 11 branches, having in 1889 a total length of 199.36 km., cost, on an average, 62 584 marks per kilometer. The annual receipts per kilometer were 4 673 marks, the expenses 3 059 marks, or 65.40% of the former. The capital paid 2.58% interest.

According to information obtained from the Royal Saxon State Railroads, these roads have proved highly suitable, and their gauge has rendered it feasible to confer the benefit of railroad connection, without a disproportionate expense, on villages remotely situated in side valleys and cut off from main lines by mountain chains.

11th. The Bari-Barletta Railroad in Italy, 0.75-m. gauge, carried 378 790 passengers and 94 100 tons of freight in 1886–87. During October the traffic amounted to 41 863 passengers and to 8 010 tons of freight, giving a yearly capacity of 500 000 passengers and of 96 000

tons of freight. The trains are composed of 10 to 12 passenger cars, and run at speeds up to 39 km. per hour.

12th. The Bolivian railroad from Antofagasta, on the shores of the Pacific, through the desert of Abacama to Ujuni and Oruro, has been in operation for two years up to Ujuni, in a length of 615 km.; it is being extended to Oruro, and the intention is to continue it later on the Bolivian high plateau to La Pas in the north, and to Suere in the east. The road has a gauge of 2½ ft. (0.76 m.), and is undoubtedly the most remarkable instance of a high plateau railroad. There are running over it at maximum grades of 3% even Pullman cars of 15-m. length; with two four-wheeled bogie trucks, transverse seats and a middle passage, and passenger cars 9 m. long on three transversely movable axles, with longitudinal seats and a center aisle.

13th. The railroad from Morvi, in Asia, 2½-ft. (0.76-m.) gauge, 94 miles (151.25 km.) long, has been in operation for five years. The annual average traffic amounts to 225 000 passengers and 22 200 tons of freight. There are regularly two daily trains in each direction, and the yearly operating expenses are 3 294 francs per kilometer or 64% of the income. The capital pays an interest of 4½ per cent.

14th. It may be finally mentioned that, in order not to burden the State finances too heavily and to make the income meet the expenses, it is intended to adopt the 0.6-m. gauge for the Peloponnesian railroads, on which a light traffic only can be expected. The cost is not to exceed the sum of 20 000 francs per kilometer under any condition.

II.—The alleged objection of the greater operating expenses of narrow-gauge roads, which are said to increase in proportion to the decrease of the gauge, is, according to the experience of practice, just as poorly founded as the objection that the smaller radii offer a greater resistance to the passing of vehicles. The latter has also been refuted by theoretical considerations and by actual experiments.

The cost of construction of German narrow-gauge railroads, with a total length of 1 051 km., gave an average of 52 124 marks in 1890–91, a comparatively very high sum. The annual working expenses averaged 3 210 marks per kilometer or 68.01% of the annual receipts of 4 721 marks per kilometer; the invested capital paid, therefore, 2.6%, which result would undoubtedly have been much more favorable if narrow gauge had been used.*

* Stat. d. in Deutschland im Betr. stehenden Eisenb. per 1890–91, Reicheisenbahnamt. Dr. Röll's Encycl., f. d. ges. Eisenbahnw., II Band, 1890.

The objection frequently raised that no cattle transports are possible on narrow-gauge secondary roads has also been removed by the fact that on the Bosna and on the Bosnian-Herzegovinian State Railroad, 0.76-m. gauge, four head of cattle or four horses are loaded into covered freight cars, 6.7 m. long, 1.66 m. wide and 2.15 m. high, and are transported without trouble. There are regular transports of cattle also on the Ocholt-Westerstede Railroad, 0.75-m. gauge, on the Broehl Valley Road, 0.785 m., and on the Salzkammergut Railroad, 0.760 m., and even on the Décauville Railroad, 0.6 m., the use of combination cars, 9.8 m. long, 1.7 m. wide, weight 4.7 tons, and of covered box cars, contents 20 cu. m., has proved a success for the carrying of cattle. The circumstance that approaches or inclined planes are dispensable in loading deserves special mention.

III.—The difference of gauge is an undeniable disadvantage in connecting with existing or projected standard-gauge roads, as an immediate passage of the rolling stock is impossible, and a changing of cars for passengers and a reloading of freight becomes necessary. But this drawback loses importance, if one decides to render possible a mutual exchange of cars by mechanical appliances. It must be mentioned, however, that their use necessitates the clearance profile of standard-gauge roads and so obliterates one of the essential advantages of narrow-gauge roads. If interchangeable car bodies, lifting derricks, etc, are used, the cost of rehandling becomes higher than with the ordinary system of reloading from car to car by hand. The International Railroad Congress in Paris in 1889 resolved that it is the simplest and cheapest to reload goods from car to car without mechanical apparatus.*

The above disadvantage does not at all enter into consideration where isolated roads are concerned, or those which are to form a new narrow-gauge system. The traffic of such roads is limited, there is no through traffic, and generally only the local traffic of the countries or provinces reached by the system has to be subserved. From an economic point of view, the secondary roads must be regarded as industrial enterprises, and their mode of operation must therefore bear a proper relation to the necessary requirements and special exigencies of each line, so as to economize as much as possible.

Moreover, the passengers ordinarily change cars at the junction

* Compte rendu sommaire du congrès international des chemins de fer, Paris, 1889.

stations of branch railroads of even the same gauge; and all cars not fully loaded, as well as express and parcel goods, are unloaded anyway, to avoid the payment of the high rent charged for the use of strange cars. The change of cars and the reloading of freight cannot therefore be regarded as unqualified disadvantages of the difference of gauge, as the reloading causes a maximum outlay of 18 to 30 centimes per ton, according to the nature of the freight, which is certainly less than the usual car-rent paid to the connecting road. Generally, the cost of reloading fully loaded cars has to be estimated at 200 to 300 francs per kilometer for a road 30 to 40 km. long, a sum far outweighed by the savings in construction and operation of narrow-gauge roads. It is evident that the necessity of reloading goods cannot form an essential obstacle to their development and earning capacity.

Some engineers regard as a technical disadvantage of narrow-gauge roads the supposed impossibility of using stable engines and cars on account of the narrow basis; engines and cars are further said to oscillate more, influencing the wheel pressures unfavorably, which would become objectionable very soon at a rapid and prosperous development of a railroad system; the small radii finally hinder an increase of speed.

The experiences of narrow-gauge roads prove, however, that the construction of rolling stock has already been so developed that those objections must be considered as not existing, which may be also inferred from the three tables, A, B, C, of the principal dimensions of locomotives, passenger and freight cars of different narrow-gauge roads, of the efficiency of locomotives, the dead weights of cars and their loading capacity. Investigations show that, even with the narrower gauges, the center of gravity lies very much lower, on account of the smaller wheel diameter, than with broader gauge cars; on the Décauville cars, 0.60-m. gauge, for example, it lies only 0.39 m. above the rails. The oscillations of narrow-gauge cars, running at the low speed of about 25 km. per hour, are very insignificant in any case. The train resistance in curves may be essentially reduced by a suitable selection of the wheel-base and the use of movable axles or of trucks and further by running short and light trains; it is, therefore, less injurious and dangerous than with standard gauge.

The question of the most suitable gauge for a certain volume of traffic, considering cost of construction and earning capacity, has long

occupied engineers and capitalists. The opinion is gaining more and more ground that standard-gauge roads are too large and expensive for a limited traffic, and that narrow-gauge roads have proved a quicker, better adapted and more satisfactory means of communication than standard-gauge secondary roads, which are shaped after the large railroads in their whole mode of construction, operation and administration.

Resolutions of the International Railroad Congress, 1885–1892.—The first International Railroad Congress adopted, in 1885, the following resolutions on the above issue :*

1st. "Secondary and vicinal railroads are to be considered as feeders exclusively, and shall be so constructed as not to deviate from their purpose.

2d. "Secondary railroads are to connect with the neighboring trunk lines ; they shall be received favorably by the administration of State and private railways, and shall find co-operation regarding :

"(*a*) The arrangement and distribution of expenses of joint depots;

"(*b*) The handling of incoming and outgoing freight;

"(*c*) The raising of capital for first construction under the most favorable conditions ;

"(*d*) The arrangement for transportation of construction material ;

"(*e*) The repairs of rolling stock.

3d. "Vicinal railroads shall be built on already existing highways, wherever circumstances permit.

"The Congress expresses the wish that the States, provinces and counties accord to the enterprises every relief compatible with wagon traffic concerning the utilization of the roads for track laying and depot construction as well as regards operation.

4th. "The Congress recommends the adoption of narrow gauge for secondary roads, as this will result in savings in construction and operation unattainable with standard gauge. It desires, further, that certain types of narrow gauge, for example, 0.75 or 1 m., be introduced universally, to the exclusion of intermediate gauges ; finally, that adjoining railroads of the same section of the country, which may enter into mutual traffic relations, use the same standards of gauge, draw and buffer appliances.

5th. "The Congress gives as its opinion, that the necessity of reloading cannot be considered as an obstacle to the development of narrow-gauge roads.

6th. "The Congress desires the greatest elasticity of the tariffs of

* Compte rendu général du congrès de chemin de fer. Bruxelles, 1886.

vicinal roads, according to the special conditions of each separate line, and wishes that the Governments fix their maximum tariffs considerably higher than those of large railroads, and afford to the incorporators more freedom in the use of the tariffs as well as the greatest possible easements in the specifications for construction and operation."

The Second International Congress, held at Milan in 1887, has ratified the above principles.*

At the International Railway Congress in St. Petersburg, August, 1892, the following question, XXXIV, was opened for discussion :†

A. "Which is the most favorable gauge for economic railways (*des chemins de fer économiques*) in the different cases (1.44, 1, 0.75 or 0.60 m.) ?

"What are the circumstances and considerations giving preference to a certain gauge ?

"Is there sufficient experience on this question ?"

E. Radice, Technical Director of the Tessin Railway, acted as referee. To his printed report are annexed the reports of H. Fromm, Managing Director of the Dortmund tramcar lines, and of de Backer, General Director of the Economic Railway Company in Brussels, made, respectively, at the fifth and sixth general meetings of 1890 and 1891, together with the discussions held at these meetings. The latter will be considered separately.

The first part of the question, on the most favorable gauge for economic railways, created a lively debate. Several members declared themselves against the 0.6-m. gauge, because, in their opinion, it did not permit the equipment of the cars with the convenience desirable for travelers, and because trains could be run at low speed only. With 1-m. gauge, railroads use speeds of 50 to 60 km. per hour, inadmissible with a narrow gauge.

Others, however, were of the opinion that speed is not an excessively important factor in most cases, and that, if in some countries 1-m. gauge has been adopted for extended lines, such roads cease to be secondary roads ; they will then be managed, operated and maintained like large railroads. Gauges less than 1 m. suffice fully for short lines. They claim that the gauge is not only a function of the speed, but much more of the first cost and of the maintenance ; nature and importance of the traffic must further be considered. Experience

* Conclusions du congrès international des chemins de fer. Milan, 1887.

† Question XXXIV : Largeur de la voie des chemins de fer économiques. Bruxelles, 1892.

teaches, moreover, that even narrow-gauge roads are able to handle a very considerable and brisk traffic.

The following resolution was finally agreed upon :

" It is important for the evolution of secondary roads that the greatest liberty be left in the selection of the gauge. Each may be advantageous according to local conditions. It is a question to be solved from case to case, inasmuch as the special demands of a locality, the nature and the extent of the expected traffic have to be taken into account in order to justify a more or less expensive maintenance. But it is just as important that some defined standards be adhered to, which have already found a successful use in practice. The four types of 1.44, 1, 0.75 and 0.60 m. are the only recommendable ones." *

Resolutions of the International Permanent Tramcar Society, 1890–92. At the fifth general meeting of the International Permanent Tramcar Society, held in Amsterdam, the following resolutions were adopted on the question:

" What is your opinion and what personal experience do you possess concerning the most suitable gauge for steam tramcars, viz.:

" (*a*) Standard gauge ?

" (*b*) Medium gauge (about 1 m.) ?

" (*c*) Narrow gauge (about 0.75 m.) ?

I. " Narrow gauge is to be chosen for steam tramcar roads, except in some cases, especially where short lines connect with standard-gauge roads and have to handle a large and bulky traffic.

II. " Concerning a selection between the different narrow gauges, it appears that they do not offer advantages or disadvantages sufficient to entitle one or the other to preference. Experience shows that one and the other have been used almost simultaneously, and that both have given good results. A predilection seems, however, to grow for the 1-m. gauge."†

At the sixth general meeting, August, 1891, in Hamburg, no conclusion was arrived at, after a very heated discussion, on the question :

" What are, in your opinion, or according to your experience, after the adoption of narrow gauge for a railroad, the relative advantages or disadvantages of the three most commonly used narrow gauges : 1, 0.75, 0.6 m. ?"

It was resolved to put this question again on the programme of the next general meeting.

For the seventh general meeting, which was to be held in Buda-Pesth

* Z. f. Eisenb. u. Dampfschifffahrt, No. 38, 1892.

Conclusions et renseignements divers du congrès international des chemins de fer. Bruxelles, 1892.

† Prot. d. V. Gen. Vers. d. Intern. permanenten Strassenb. Ver. Brüssel, 1890.

in September, 1892, the writer was chosen referee on the above question, but the meeting did not take place for sanitary reasons. The author's comprehensive printed report on the subject comes to this final conclusion :

" The gauge is to be fixed separately for each case after mature deliberation, on the strength of accurate investigations on the present and expected demands of traffic and under full consideration of all local conditions and of the financial and other means at hand.

" Proper regard is further to be had for an economical construction and a simple and cheap system of operation, in order to insure a suitable percentage of interest for the expended capital." *

Principles for Construction and Equipment of Local Railroads Within the Sphere of the German Railway Union.—It must not be left unmentioned that the German Railway Union, in establishing principles for the construction and operation of local railroads, has recommended the 0.75-m. gauge for narrow-gauge roads according to the resolutions of Constanz, June, 1876; of Salzburg, July, 1886; and of the Berlin Engineers' meeting, May, 1890; it has consequently abandoned a uniform as well as the 0.6-m. gauge.

The code of rules for German railways of inferior importance, July 12th, 1878, fixes also the gauge for narrow-gauge roads at 1 or 0.75 m. Exceptions are admissible with authorization of the Government and with concurrence of the Railway Department.

Specifications for "Small Railroads" in Prussia, for which Gauges of 0.60, 0.75 *and* 1 *m. are Admissible.*—The above ordinances have, however, been modified by the new Prussian law, July 28th, 1892, on "Small and Private Connecting Railroads (Tertiary Railroads)," and the specifications of the Secretary of the Department of Public Works, November 18th, 1892, appended to the law, exact that, in the interest of the defence of the country, the ensuing regulations will be enforced on all railroads operated by engines:

I. Tracks.

(*a*) Besides standard gauge, only 0.60, 0.75 and 1 m. gauges are to be permitted.

(*b*) Where ties are used, the minimum weight of rails must be 9.5 kg. per meter

(*c*) For the 0.6-m. gauge the smallest radius is to be 30 m.

(*d*) The inside clearance of rails at switches, crossings, crossovers, etc., must not be less than 0.035 m. (Regulations "*c*" and "*d*" do not hold good for tramcar roads.)

* Bericht d. Civ. Ings. E. A. Ziffer, f. d. VII Gen. Vers. d. Intern. perm. Strassenbahn Ver. Brüssel, 1892.

II. Rolling Stock.

(*a*) For roads with 0.6-m. gauge, locomotives and cars must be able to pass 30-m. curves without trouble.

(*b*) Wheels are to have one flange only.

(*c*) The rolling stock of railroads with 0.6-m. gauge must be equipped with central buffers, 0.30 to 0.34 m. above top of rails. The loading capacity of cars, given in kilograms, must be a multiple of 500.

III. Depots.

Where railroads with small gauge join such with larger gauge and a passage of cars is impossible, suitable arrangements for the transfer of goods are to be made. Where an existing line is being extended, the maintaining of gauge and weight of rail may be permitted, even if neither should conform to Regulations I, *a* and *b*.*

Introduction of the 0.6-m. Gauge on All New "Small Railroads" of Mecklenburgh.—The Diet of Mecklenburgh has ordered the introduction of a uniform gauge of 0.6 m. on all new "small railroads." At the discussions, the fact was referred to that this is the standard gauge for the Prussian military administration, especially on fortress railroads; it was further stated, that influential French circles had emphasized the necessity of first considering the defence of the country in building "small railroads," and that, as France possesses a great number of 0.6-m. gauge roads, the result of the French deliberations has been to establish the principle to use 0.6 m. only, and to take standard gauge at once if a larger gauge should become necessary.

The Friedland "Moorcultur" Railroad and the "small" road from Friedland to Vorpommern have given eminent satisfaction, and their operation is entirely safe for passenger as well as for freight traffic. The danger of a tilting of the cars, which are built on the truck system, does not exist. The 0.6-m. gauge is further unobjectionable as regards speed. On the Friedland road this is limited to 14 km. per hour; but a similar "small" road in Sweden, near Kosta, which has been in operation for seven to eight years, runs trains at an hourly speed of 35 km. with authorization of the Government.†

Final Conclusions.—In summarizing the investigations, experiences and conclusions on railway gauge, we find that standard gauge has been adopted in the European States for trunk lines, with the exception of Russia, Spain, Portugal and Ireland, which use a broader

* Verordnungsbl. d. k. k. Handelsmins. f. Eisenb. u. Schifffahrt No. 144. Dez., 1892.

† Z. d. Vereins deutscher Eisenbahnverw., No. 98, Dez., 1892.

gauge in addition to standard, and Greece, which uses a narrower gauge; in the other countries, broad, standard and narrow gauge exist, and either the one or the other is in exclusive or prevailing use, or, generally, all three systems find use. The fact deserves attention, that in the younger, principally the transoceanic countries, narrow gauge has, from economic reasons, been also taken for main lines; in these cases 1-m. gauge has preferably been chosen.

For secondary (local and vicinal) railroads, as well as for all roads of inferior importance which subserve limited interests and accommodate principally local traffic, standard and a great variety of narrow gauges have been adopted. The latter have been chosen in just appreciation of their economic advantages in construction and operation, and in spite of prejudices propagated from different quarters, frequently even by engineers, and of a systematically conducted opposition against the narrow gauge. Their great advantages, especially from the standpoint of economy and earning capacity, are, however, indisputable, though it must be admitted that, due to a few minor disadvantages of narrow gauge, standard gauge may become desirable for secondary roads; for instance, where existing standard gauge roads are to be connected or extended, where the country is perfectly level and right of way unexpensive, or where, by utilizing broad and level highways, any acquirement of real estate is avoidable.

Generally, the narrow gauge may be regarded as the most rational solution of the question of a simple and cheap construction and operation of secondary roads, even for a not inconsiderable traffic.

Likewise, narrow gauge is also to be recommended for main lines in countries with a presumably moderate traffic, and where the financial status necessitates the greatest possible economy, so that the invested capital may pay a good interest as quickly as possible.

It remains now only to select a suitable gauge for narrow-gauge roads. The writer thinks that only the three gauges 1, 0.75 and 0.60 m., which have found the most extended use so far, should be taken into consideration; but he also believes it very dangerous to recommend the exclusive use of one or two gauges, or to prohibit the introduction of one of them. The selection of the gauges is, therefore, after careful commercial and technical investigations, to be made dependent on the demands of the present and expected traffic, on its nature and on the local exigencies, and finally on the financial and other means

at hand ; the presumable earning capacity of the investment has to be fully considered. The gauge must be determined in each separate case after a mature deliberation of all existing circumstances.

It must further be acknowledged that narrow-gauge roads, even with 0.6-m. gauge, can accommodate a large traffic, and that they always require a smaller outlay. It is finally apparent that, if secondary railroads are to continue in a successful development, they must enjoy full liberty regarding construction, operation and administration, and must be built, organized and managed on standards different from those of main lines.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

622.

(Vol. XXIX.—August, 1893.)

RAILWAY SIGNALING.

By G. KECKER, Betriebs-Director Imperial Railways at Metz, Germany.

Translated from the German by GEORGE F. SWAIN, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Although the question in railroad signaling between the system of time intervals and that of space intervals has been universally decided in favor of the latter, yet there are still some very important matters regarding signaling which, on account of fundamental differences, may be worthy of a detailed discussion. The first point relates to the use of colors for night signals.

According to general usage, red means danger, "stop"; green means caution, "run slowly," and white means "all clear." The disadvantages of white light, however, have induced many companies to abandon its use at fixed signals, replacing it with green as a safety signal. This system has the advantage that in case of accident or breakage to a colored screen or glass, white light appears, which is considered a danger signal; whereas, if white is a safety signal, the breakage of a red glass or lantern may result in a false signal. This can occur, for example, in the case of the distant signals of the German

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

signal system, and in those of the American block systems of Hall, and the Union Switch and Signal Company.

This diversity of practice is therefore accompanied also by some further differences, for while the English distant signal acts as an imperative signal to stop, the distant signals just named simply indicate the position of the following home signal.

There is further a substantial difference between the German practice of operating signals on one mast and the practice in other countries. In the latter there are just as many semaphores or lanterns above one another as there are branches from one approaching track, all of these in their normal danger position being visible and showing red light at night, while in the German system the upper arm only is visible and shows red light at night. Where it appears necessary to control the movement of trains to a branch by signals on the same mast with other signals, the mast is provided with two or three semaphores and the same number of lanterns, one above another. The lower semaphores and lanterns are used only to give safety signals to a train diverging from the main line; in case of a signal to stop, or in case of a signal to proceed on the main line, the lower arms are vertical and the lanterns are invisible. By this arrangement the locomotive engineer never passes a red signal; but it has the disadvantage that an all clear signal gives no information as to which track is clear. The number of semaphores is, moreover, limited to three; if a greater number is required, they must be placed upon more than one mast. This limitation does not exist outside of Germany; one mast, especially at large terminal stations, often carries four or more semaphores, which give a very clear idea, not only of the number of diverging tracks, but also in regard to their directions.

Finally, a marked difference exists in the operation of signals at stations.

In England and America the different portions of a station and yard are independent sections, protected in all directions by signals, and to which the intermediate station tracks bear the same relation that the tracks of the main line bear to the adjacent block stations.

In Germany, on the contrary, the entire station is considered as a whole. The entire operation of signals and movement of trains at the station is made dependent upon one officer, who also, as a rule, has charge of the dispatching of trains.

In order to secure the dependence of the operators in the towers upon the orders of the managing officers of the station, there are special block appliances, which are operated from a suitable office in the station building.

PART I.—IN GENERAL.

1. Introduction.
2. Signal systems.
   System of time interval ; system of station or space interval.
3. Signals in themselves.
   Discs ; semaphores ; colors for signals ; reflecting signals.
4. Apparatus for operating signals.
   Rods ; wires ; wheels ; Austrian distant signals ; Hipp's signal ; Dumont and Postel-Vinay ; Hall's signal ; Currie and Timmins; Union Switch and Signal Company; American Pneumatic Company ; Bianchi and Servettaz.
5. Fog signals.
   Torpedoes ; bells ; alarms ; fog horn ; apparatus acting on the engine.
6. Control or tell-tale apparatus.
   Duplicate signals ; ringing apparatus ; signal repeaters ; galvanoscope ; control of illumination of signals.

IN GENERAL.

Introduction.—When it is remembered what an important and indispensable factor signaling is in the operation of railroads to-day, that engineers are constantly striving to perfect it in every direction, that every force of nature is utilized and every new discovery at once applied, it can scarcely be realized that the first railroads in England were operated without signals. Yet such was the case. The first railroads, however, were on about the same plane as the horse railroads to-day. Moreover, they were operated only during the day and generally with but one engine, and the speed was not over 10 miles per hour (16–17 km.)

Further, the Manchester and Liverpool Railway, which was opened September 15th, 1830, had engines without whistles ; they, therefore, lacked even the signal of which M. M. von Weber in his book, "Railroad Telegraphy and Signaling" (which although old is still readable), says that it seems to us now the very voice of the railroad system,

whose tones show its whole character, and to which the soft tones of the post horn compare as the poetry of travel in early times compares with the restless travel of to-day.

An accident led George Stephenson to conclude that his engine could make 22 miles per hour, but that in order to exceed this speed a clear track must be provided. This led Stephenson to introduce a special signal system, in which he made use principally of colored discs on tall poles, which were held or turned by special watchmen. When, in 1836, it was found practicable to run at night, colored lanterns were fastened to the poles, which were used in the same way as the colored discs in the daytime. The trackmen were provided with red or green cloth flags, with which they could signal a train to stop or to run slowly where they considered it necessary.

Railroad signaling, not only in England, but in other countries, was developed from this idea of Stephenson's. It would carry us too far, and exceed the limits of this paper, to follow all the changes in the development of signaling up to the present day. The writer will, therefore, confine himself in the following pages to giving an idea of the present condition of signalling in the various civilized countries.

Systems in Signaling.—In general, signal systems may be divided into two almost diametrically opposed classes.

The first and original system is that with a time interval. It prevents the too close approach of trains running in the same direction by providing that they shall follow each other only after stated intervals of time, and that the following train shall be signaled to proceed slowly or to stop, unless the prescribed time interval has elapsed since the passage of the previous train. The time interval varies with the speed of the trains. This system was soon proved unsafe by the occurrence of several bad accidents arising from the fact that the signal men were not always reliable, or that they could not always give the signal at the right time. The introduction of electricity, moreover, made it possible to abandon the system of time interval, and to substitute that of a space interval between trains, independent of their speed.

The fundamental principles of these systems, both of which are still in use, may be thus summarized:

1. *Time Interval System.*—The track is clear if no signals are shown. A visible signal does not mean "stop," but allows a train to proceed with caution.

The block system, so far as introduced, is not an absolute block, since it allows more than one train or engine to be in the same section and on the same track at the same time.

2. *Space Interval System.*—The track is normally blocked; the visible danger signal is changed to a visible safety signal when the track is clear.

The block system is an absolute one, *i. e.*, only one train or engine is allowed on the same section and on the same track at the same time.

Signals in Themselves.—Signals are either audible or visible signals. The latter differ as to color and as to form.

The investigations of the brothers Chappe, the inventors of optical telegraphy, are of the greatest importance for the science of railroad signaling. Unfortunately, their results do not appear to be sufficiently known to railroad men, since they have been frequently disregarded. One of the most important results is that the color of any body may disappear under certain conditions of illumination, so that only the form and not the color can serve for a reliable signal.

For day signals, color was therefore very soon abandoned as giving any particular meaning, and it is now used principally as a means simply of increasing the visibility. A complete disc transverse to the track and turned towards an approaching train generally means "stop," while a disc parallel to the track, presenting its edge to an approaching train, means "all clear." Since the edge of a disc is as good as invisible, a disc rotating about a vertical or horizontal axis appears to be the best signal for the time interval system. The signal to proceed with caution cannot be given with the disc.

The experiments of the brothers Chappe showed further that a narrow and long surface could be seen farther than the same area in the form of a circle or a square; and that in average conditions of the atmosphere and on cloudy days, a body 6 ft. long and 1 ft. wide, projected against the horizon, could be seen by the naked eye at a distance of 6¼ miles (10 km.). The form of signal chosen by the brothers Chappe, as a result of their experiments, and which they called a "semaphore," consisted of an arm hinged at one end which was attached to a mast. This has proved a most excellent signal for railroads. It is not only more plainly visible than a disc, but in addition to the vertical position, meaning "safety," and the horizontal position, meaning "danger," an intermediate position at 45° may mean "caution."

While these signals were soon adopted by all roads as day signals, it was necessary to come to some agreement regarding the meaning of colors for night signals. This was the more important because in England frequently one railway was used by trains and engines of other railways, and it was therefore important that the same color should always mean the same thing.

In February, 1841, there was held at Birmingham a congress of English railway men, at which uniform rules for signaling were adopted, especially with regard to the meaning of colors. It was decided that red should mean "danger," green "caution," and white "safety."

In view of the fact that at the instant of danger colored objects were not always at hand, any object or light swung violently was to mean "stop."

These rules were so simple and practical that they were accepted throughout the world, and are still in general use, although with the added idea that red means "stop" and green "proceed slowly." The Birmingham convention fixed therefore the basis of our modern signal code.

The choice of colors, however, was limited. The experiments of Chappe showed that if the visibility of a white light is taken as one, that of a red light of equal intensity is one-third, of a green light one-fifth and of a blue light one-seventh.

In choosing three colors for signals, therefore, white, red and green are the best, on account of their greater visibility. Against blue may also be objected that under artificial illumination it may appear green. Since the danger signal is the most important of all, it might appear advisable to choose for it the color possessing the greatest visibility; but white lights are so frequent, especially near cities, that it can scarcely be considered as a signal. For the danger signal, therefore, the color was chosen which was next to white in visibility, namely, red, while green was taken for "caution," leaving white for "safety."

The properties of white light, however, are likely to exercise a disturbing influence in many respects. In the first place, on account of its greater visibility, it is able to partially or wholly obscure neighboring colored lights, a circumstance which may have serious results in railroad operation. Moreover, the safety signal must frequently be changed into the danger or cautionary signal, which is generally done by moving a red or green glass in front of the white light. Movable

glass blades or screens, especially if exposed to the weather, are easily broken, and should this occur, it might happen that when a signal was set at danger it might still show white light, an approaching train would get a false signal and an accident might result. Even though it should be very seldom that signal screens were broken without being noticed by the operator or the trackmen, it nevertheless seems undesirable to arrange signals in such a way that a red or green might by accident be changed to white.

When, therefore, in England, the block system was introduced, in which when a section is occupied the entrance of another train is forbidden, and when free, another train is allowed to enter with undiminished speed, the cautionary signal was discarded. This opportunity was at once seized to discard white as a color signal; and the danger signal is now red, while the safety signal is generally green. Under this system, if white light is shown at any signal, the engineer is to consider this as a danger signal and proceed accordingly, thus obviating all danger of misunderstanding. Since, therefore, only two ideas were to be expressed by signals, in the case of semaphores the vertical position (which is really no signal at all) could be also discarded, and danger expressed by the horizontal position, while safety was expressed by the inclined position. Thus the day as well as the night signals gave definite expression to the two ideas, and the semaphore became the most suitable signal for the space interval system.

Where white light has been abandoned as a signal, some slight confusion of ideas has, it is true, resulted from the fact that, while green is the safety signal at fixed signals, it has remained the cautionary signal in the case of hand signals or temporary signals where track repairs render them necessary. This disadvantage, however, considering the ease of distinguishing the two cases, may be considered to be only theoretical and of no importance in comparison with the practical advantages in point of safety, resulting from abandoning white light as a signal at permanent signals.

If white light is used, it is advisable to let it shine through an opening of $\frac{5}{8}$ to $\frac{7}{8}$ in. diameter in the center of a dark glass, *i. e.*, to make it a so called "star-light."

The experiment has repeatedly been made to provide a signal which should have the same appearance at night as in the daytime. The simple illumination of the day signal, even with the electric light, has

proved insufficient, and specially formed signals capable of powerfully reflecting the light have been found necessary. For example, the Eastern Railroad of France had at its junction points signals whose arms were illuminated at night by white light from lanterns placed in front of them; the flat surface of the arm was covered with small mirrors arranged in such a way that they each reflected the light from the lantern parallel to the track, so that the signal presented the same appearance by night as by day to the engineer of an approaching train. Also some of the signals prescribed by the new French signal rules have arms covered with small reflecting strips illuminated at night with white light.

In the *Railroad Gazette* for 1888, page 201, a signal is described, constructed by the Union Switch and Signal Company after designs of Spicer and Schreuder, consisting of a concave arm whose back surface was a slightly concave mirror with a lamp situated in the axis and which reflected the light through a glass plate forming the front of the arm. In the same volume of the *Railroad Gazette*, page 684, Koyl's semaphore is described, which consists of a portion of a paraboloid of revolution whose vertex is in the mast, while the flame of the lantern is in the focus. This is said to be clearly visible, at night and under ordinary atmospheric conditions, at a distance of half a mile, in form, position and color. It is used on the Lehigh Valley Railroad, and is said to work well.

Apparatus for Operating Signals.—The direct setting of a signal by hand is seldom possible, hence, to transmit the movement, either rigid rods or wires are used, or else electricity, compressed air or hydraulic pressure.

The fundamental principal to be observed is that a safety signal shall at once automatically go to danger in case of any failure or accident to the mechanism for transmission. It follows that every signal must be placed by positive action in the safety position, and must go by its own weight or by an attached counterweight to the danger position.

Rigid rods, 1¼ to 1½ ins. in diameter, supported by rollers every 6 to 10 ft., are simple and not more expensive than wires up to distances of 550 ft.

The effect of temperature upon the length of the rods is very simply provided for by inserting equal armed levers, dividing the en-

tire length into two or more parts, so that the length of rod exposed to tension equals that exposed to compression. In the case of short rods or incomplete compensation, the throwing mechanism is given a greater travel than is necessary to throw the switch or signal, so that a part of the travel before and after the apparatus is thrown is without effect on the position of the switch or signal.

In most frequent use are wires or wire ropes, from $\frac{1}{8}$ to $\frac{1}{4}$ in. in diameter, either single or double.

A single wire is quite sufficient for setting a signal at safety, but it has the disadvantage that a person desiring to tamper with the signal may pull the wire or raise the counterweight, and thus give a false safety signal. In fact, several accidents in Germany have been traced to this cause, so that it has become the general practice to use double wires, with which tampering with the signals is impossible.

Long wires are open to the objection that they may become more or less inoperative, or even give a wrong or dangerous signal on account of changes of length due to temperature. A wire half a mile long changes its length about 8 ins. if the temperature changes 36° Fahr., and this is almost equal to the travel necessary to reverse a signal. With long wires compensation apparatus is therefore necessary to obviate the effect of change of temperature. Simple screw connections (turn buckles) inserted in the line of wire are not sufficient, since they would require continual attention and adjustment. It has been necessary, therefore, to resort to automatic devices. On the French roads, where single wires are principally used, a very simple and practical method is employed. It consists essentially in letting the end of the wire farthest from the signal pass over a roller, keeping it in uniform tension by a weight; to throw the signal, the movement of the lever clamps and carries along the wire, which is released when the lever is reversed.

Double wires, as generally used in Germany, need, up to a certain limit, no means of compensation. The wire is given an initial average stress, after which the stress changes with the temperature, the length remaining the same. This is perfectly practicable up to a length of a quarter of a mile. For greater lengths a compensating device is employed, in which the essential idea is to have both wires strained equally by equal weights hung upon them at the middle or at one end of the line, so arranged that a change in the stress of either wire by

pulling or releasing it automatically clamps the weights and allows the signal to be operated.

To support and guide the wires, guide wheels are placed at distances of 50 to 65 ft. apart, fastened to small posts. On straight lines the wheels are vertical; on curves they are more or less inclined, in order that the wire may not leave the groove. Recently the wheels have been fastened to the posts, hinged in such a way as to be free to automatically assume the proper inclination on curves.

Electrical Throwing Apparatus.—On the roads of Austria-Hungary it is a fundamental principle to use electricity only to release or to catch the throwing mechanism, the moving of the signal being effected by this mechanism, which is actuated by a weight.

Almost all the signals used on the roads of Austria-Hungary are constructed in accordance with this principle, from the first ones sent to the Paris Exhibition of 1867, by Leopolden, to those exhibited by Langié at the Paris Exhibition of 1878, and those shown at Vienna in 1883 by Pollitzer and by Sandorf. The release is effected by batteries or by induction currents.

On the Swiss roads, a distant disc signal, made by Hipp, is frequently used, which, however, requires a separate conductor for each of the two positions of the signal. The development of electrically operated distant signals in Switzerland and in Austria has, however, been arrested in the last few years by the fact that in these countries the safety appliances used for the protection of large stations have steadily increased, and for these it is prescribed that wires shall be used for setting the distant signals.

For operating the disc signals of the Eastern Railroad of France, Dumont and Postel-Vinay have used an apparatus in which the releasing and the arresting of the mechanism is done electrically. The mechanism itself is similar to Siemens and Halske's single wheel or spindle alarm apparatus. The operation of the signal is effected by breaking or closing the current through an electro-magnet in such a manner that the signal is clear as long as the current is closed, but goes at once to danger when it is broken.

In Hall's signal the electric current serving the signal brings into action, not a mechanism, but the electro-magnet of a powerful local battery. The apparatus works with a closed circuit. The signal is given by a disc of red silk within a water-tight casing on a signal

pole. The case has a circular opening on each side facing an approaching or receding train. The disc is held in the all clear position by an electro-magnet, through which a permanent current passes. If this current is broken the red disc is released and becomes visible at the opening. In the daytime the disc is illuminated by the daylight from behind it; at night by a lantern placed behind it. Recently, according to statements of Messrs. F. Büte and von Borries, this signal is said to have been made in the form of a blade, and the colorless glass behind it replaced by a pane of ground glass. The signal then has the same appearance by day and by night. When used as a distant signal, green silk is used instead of red.

Hall's signal is extensively used on American roads, and is highly spoken of. In quite a number of electrically operated signals used in America, open circuits as well as alternating induction currents are used. They have the peculiarity that the signal arm rotates about an axis close to its center of gravity.

Noticeable also is the semaphore signal of Currie & Timmins, of London (shown at the Paris Exhibition of 1889), in which, also, the signal is set by electricity. Specially constructed tubular electro-magnets are used, which attract the armature up to a distance of 3 ins. with approximately uniform force. At night the signals are given by incandescent lamps, and for this purpose the semaphore has a contact which, according to the position of the arm, sends a current to the red or the green lamp. The bulbs are colored.

The Union Switch and Signal Company, in Pittsburg, has developed a system, devised by Westinghouse, in which compressed air is used to operate the signals. The semaphore is normally horizontal, and is held in this position by a counterweight. At the foot of the mast is a reservoir of compressed air, and on the mast is a cylinder whose piston is connected with the signal arm. When compressed air is let into the cylinder, its piston is forced down, and carries the signal to the safety position. This operation is effected by an electro-magnet, whose armature opens a valve to which it is connected. When the current is broken, a spring closes the valve and allows the compressed air to leave the cylinder, and the counterweight then carries the signal to the danger position. Any failure of the current brings the signal to danger.

The American Pneumatic Company, of Boston, has introduced an

automatic system for block and other signals, in which a current of air serves to transmit the motion. The signal is moved by a train of mechanism which is operated by the movement of a track lever. The release of the mechanism is effected by a bellows, which is set in operation by the pressure of the first wheel of the engine. The air contained in the bellows is forced through a lead pipe $\frac{3}{8}$ in. in diameter, with a velocity of 600 ft. per second, to a reservoir at the foot of the signal mast, which is closed by a diaphragm. With this diaphragm is connected the release of the mechanism. Each signal is generally connected with two pair of bellows, of which one brings the signal to safety, the other to danger.

By the arrangement just described, not alone signals, but other signal apparatus, can be operated, such as screens, alarms, and even crossing gates. On the pipe from one bellows 6 to 8 connections can be made, provided they are all to be operated in a certain direction at the same moment.

Recently the Italians Bianchi and Servettaz have made successful attempts to use water, though inelastic, to transmit the motion for setting switches and signals. To prevent freezing it is mixed with glycerine. The water is stored in an accumulator under a pressure of 50 to 60 atmospheres. The movement of a switch is effected by means of two simple cylinders having the same piston. For operating a signal one cylinder is sufficient, the hydraulic pressure giving the safety signal, while the signal is carried to danger by a weight when the pressure is removed or in case a pipe breaks.

Fog Signals—The worst enemy of safe railroad operation is fog, which not only prevents the engineer from seeing the track ahead, but also obscures danger signals. Various means have been tried to remedy this evil.

Thus far the most successful are torpedoes, of which for safety two are placed upon the rail at a suitable distance in front of a danger signal, and which must be removed when the signal goes to safety. Torpedoes are used to signify "stop at once."

The repeated putting on and taking off of torpedoes is rather troublesome if it is done by special watchmen. The danger of mistake and the danger of walking on the track in a fog have led several roads to have recourse to special devices by which the torpedoes are placed upon and removed from the rails by mechanical apparatus interlocked

with the signals. But even these devices are open to the objection that they require personal attention in order to replace at once every exploded torpedo with a fresh one. The attempt has therefore been made to do even this automatically, within certain limits, and also to remove the uncertainty attending the blow struck by the rolling wheels. To accomplish the last result a special striking apparatus is introduced between wheel and torpedo, as in the "revolver torpedo" of Scholkmann and the torpedo signal used on the New York elevated roads at turnouts and crossings. In the first named, 12 pair of torpedoes are placed in a drum, thus serving for quite a series of signals; in the latter the torpedoes are replaced automatically from a supply chamber.

Another kind of fog signal consists in connecting the distant signal with a bell having one or two hammers, which rings when the signal is at danger. The motion of the hammers is derived from a track lever which is alternately depressed by each wheel of the train and raised by a spring. When the signal is at safety, the lever is depressed so as not to be touched by the wheels.

On the Government roads of Alsace-Lorraine the signal disc of a distant signal is replaced by a shallow bell against which the hammers strike when the signal is at danger. The bell is horizontal when the signal is at safety.

On other roads alarms are in use like those of alarm clocks. They consist essentially of a clockwork actuated by a weight, which is released by means of a lever close to the rail. The bell is struck rapidly by a hammer, and rings until after one revolution of one of the gear wheels it is automatically stopped.

The firm of Max Jüdel & Company, in Brunswick, has recently proposed to improve distant signals by the addition of a fog horn, which is to be blown by a pair of bellows operated by a track lever close to the rail. It is a remarkable fact that the fog horn is more effective when the sound follows the train than when the horn is blown in front of the train.

Other devices are those intended to operate directly upon the locomotive whistle or upon the train brakes. All these devices, however, require, in addition to an appliance between the rails which is raised or lowered according as the visible signal is at danger or at safety, a special mechanism in the locomotive, which, when the distant

signal is at danger, comes in contact with the raised bars between the rails, and blows the whistle or sets the brakes. The necessity of applying such apparatus to every locomotive which runs over the road limits the general application of this kind of device.

Tell-Tale Apparatus.—It is of the greatest importance that the man operating a signal shall be assured that the signal has actually taken the desired position. This is easily attained in the daytime when the signals are near by. In order to inform him with certainty at night, the lamp is allowed to shine backwards as well as forwards, with different colors, according to the position of the signal, excluding, however, the signal colors red and green.

When the signal is farther away, or when it is invisible to the operator on account of intervening obstacles, special devices are necessary which, partly mechanically and partly electrically, inform the operator or station agent of the position of the distant signal. The mechanical devices consist of duplicate signals, which follow the motions of the principal signals, but are set up in view of the operator. In course of time these have been discarded as too unwieldy, and at present electrical apparatus is principally employed.

The simplest, yet absolutely reliable, device is the bell generally used on the French roads, called "Trembleuse." These bells stop automatically ; they ring only when an electric current passes through the tell-tale circuit. When the distant signal is normally at safety, the current is broken, and is only closed when the signal goes to danger. As long as the bell rings the operator is sure that the signal is at danger.

Similar tell-tale bells are used on the Austrian roads.

For signals which stand normally at danger, these bells are not suitable, since they cannot be rung continuously; while if the circuits are changed so that they only ring when the signal is at safety their silence would afford no security that the signal really was at danger. Moreover, if they ring almost without interruption they are often unendurable. F. Gattinger has therefore constructed an automatic current breaker which by means of a swinging disc or a pendulum only closes the current, say, every second.

In England visible tell-tales are universally used which not only indicate the position of the signals, but also show the operator an actual view of the signal itself, and are therefore called "signal repeaters."

An excellent tell-tale is the galvanoscope, if properly arranged ; in this, however, as in all electrical tell-tales, one position of the signal should not be indicated by an interruption of the current, since the same effect might be produced by a break in the circuit. On the other hand, there ought to be a current in the circuit, both when the signal is at danger and when it is at safety, while a third position shows a break in the current or some accident to the circuit.

It is also of the greatest importance that at night the signal lanterns be really lighted. In most cases this is assured by simply letting the lanterns throw their light backwards as well as forwards. The position of the signal, however, may render this simple means impossible. In such cases, electrical control apparatus is made use of. This consists in a contact apparatus in which the making or breaking of the current is effected by the change of length of metal strips, due to the burning or extinguishing of the lamp. The contact apparatus must be very delicate in order to indicate after a few seconds the extinction of the lamp. In the operator's room there is an indicator consisting of a galvanoscope which, when the current is broken, shows behind the little window of the case a colored disc with a notice such as "light out." Sometimes, also, alarms are inserted in the circuit, which ring when the lamp goes out.

Part II.—Application of Fixed Signals.

1. English signal system.
   Distant signal; home signal; station signals.
2. Belgian signal system.
   Distant signal.
3. French signal system.
   Circular discs; protection signal; square signal discs; junction signals; facing switch signals.
4. German signal system.
   Continuous line signals; distant signals; home signals; mast signals.
5. Position of signals.
   Distant signals; local or home signals; station signals.

1. *English Signal System.*—In foggy England, where in order to avoid highway grade crossings the railways lie frequently in deep cuts, and have many curves, it was soon found that, in order to surely

prevent accident at any point of danger, it was necessary to place the corresponding signal at a considerable distance from this point. Thus arose the "distant signal," which is a characteristic of the English signal system. By its means head and rear collisions were guarded against, long curved cuts and tunnels that could not be seen through were protected, and it was also possible to communicate definite information or instructions to points a long distance away, or when a station or other portion of the track was blocked, to prevent a too close approach of trains to each other.

In the congress at Birmingham, already mentioned, it was agreed that signals should normally stand at danger.

If the distant signal is at danger it presents to an approaching train by day the full round disc or the horizontal blade, and at night red light. If it is at safety, the disc shows only its edge, or the semaphore is inclined at 45 to 60°, or at night green light is shown. If a locomotive runner sees his distant signal at danger, he must at once shut off steam and apply the brakes, so as to be able to stop at the distant signal. If he then sees that the track is clear, he is to proceed slowly, covered by the distant signal, always keeping his train under such control that he is able to stop quickly if any obstacle appears.

If a train has run by the distant signal, and is near the point of danger (the end of a section in the case of the block system, or the switch in the case of a junction or the entrance to a station, or a grade crossing, etc.), it is then necessary to give the engineer definite orders as to his future movements. For this purpose a "home" signal mast is erected at a suitable point near the point of danger, carrying a blade distinguished from that of the distant signal by having a square end while the distant signal blade has a notched end.

If several tracks diverge from one main track, as many blades are generally placed above one another on the home signal mast as there are tracks for an approaching train. The rule is that the blades from top to bottom correspond to the tracks from left to right.

At night, the home signal shows the same color as the distant signal. No engineer is allowed to run by a home signal at danger.

Station signals are generally placed behind the home signals at block, junction, or other stations, and regulate the departure of trains. They resemble the home signals completely in form and meaning.

2. *Belgian Signal System.*—On the Belgian roads the signal system

has been developed quite closely after the pattern of the English. The home signals are precisely the same, in form and meaning; the distant signals, however, differ in form considerably from the English. They are in the form of discs, to distinguish them better from the home signals; and in order that they may conform to the principle of giving definite signals for safety and danger, they show when at danger an elongated rectangular blade, or at night red light, and when at safety they present a square disc, or green light.

3. *French Signal System.*—The distant signal was adopted in France in its original form of a rotating disc, and this form has been preserved to the present day. Indeed, France is the country in which the fewest experiments have been made in signaling. The French roads are even to-day operated for the most part by the system of time interval, and this system has become such an integral part of the French railroad system that notwithstanding its defects, comparatively good results are attained with it. In consequence, safety is generally indicated by the absence of signals.

In addition to the distant signal, the original English color code was adopted, so that in France red stands for danger, green for caution, and white for safety.

Semaphores as distant signals have been used only on the Lyons road.

When the French distant signal is at danger, it shows a circular disc or a red light. In the safety position the disc is parallel to the track, and white light is shown at night. When an engineer sees a disc or a red light, he must at once reduce speed and proceed only at such a speed that he is able to stop within the length of track in sight, should he see any obstacle, or another danger signal. In any case the train must be brought to a stop either before the first switch or the first crossing of railway or highway, or before the point for which the disc serves as the signal, and it can only proceed under further signals or verbal instructions from the conductor or the station master.

To each circular disc corresponds a protection signal (*disque de protection*), illuminated at night, which shows the point beyond which the disc affords protection, except in bad weather. If, therefore, a train which has run by a disc signal stops before its rear has reached the protection signal, it is not to be considered as sufficiently protected in the rear.

Besides these, square (home) signal discs are in use on the French roads, which are located close to the points to be protected. When these show the full disc, or at night a double red light, they command an immediate stop.

The normal position of the distant signal is at safety, but it stands at danger, of course, as long as the home signals at danger.

Junction points of French roads are protected by distant signals, which present the same appearance by day as by night, namely, in white letters on a green field the word "Bifur" (caution). At such signals the engineer must prepare to stop, should it be necessary, at the square home signal for which the junction signal is the preparatory or distant signal.

Finally, signals are erected in front of every facing switch (*signal de direction*). These signals consist of a mast upon which are placed as many arms, one above the other, as there are diverging tracks. The arms, from top to bottom in order, refer to the tracks in order from left to right. The arms are hinged at their centers of gravity, and can assume only two positions, viz., the horizontal, which is a stop signal for the track to which it refers, and the inclined position, which denotes that the switch is set for the track in question. At night, the horizontal arms show violet light, the arms inclined obliquely downward show white light, or green light if the switch is to be taken at a reduced speed.

On approaching a junction or a facing switch provided with signals, the engineer must indicate the track he desires to take by a corresponding number of long blasts of the whistle, without regard to the position of the signal.

4. *German Signal System.*—The lack of political unity in Germany at the time when railroads were introduced affected many things unfavorably, and especially the signal system. M. M. von Weber, in his time, counted on some 60 railway systems over 90 different ideas to be given by signals, for which more than 1 000 different forms of signals were provided. A voluntary association—the Germany Railway Association—endeavored to bring order out of the chaos which existed in the railway system, and succeeded so well that even before the political union of Germany its standards were generally recognized, and the association itself comprised, not only all the railroads of Germany, but also roads in Austria-Hungary, Luxemburg, Russia, Holland and Belgium.

The signal code for German railways adopted by the Bundesrath, July 5th, 1892, to go into effect January 1st, 1893, contains 35 signal ideas, for which 65 forms of signal are allowed.

Characteristic of the German and still more of the Austrian signal systems are the continuous signals of the approach of a train. The English roads, with their heavy traffic, and also the French roads, adopted the principle that the road must always be in a condition as if a train were expected. But in Germany, in consideration of the many grade crossings, it was thought desirable, before a train left any station, to notify the next station and all the line employees (gatemen, etc.) between the two stations.

On the English roads each section of track is protected by a distant signal which is normally at danger, and is only placed at safety to allow the passage of a train, after which it is at once returned to the danger position. On the French roads, the track is normally clear, and is protected by a danger signal whenever there is anything to prevent the passage of a train, such as a grade crossing at which the gates are open, or when shifting is going on upon the tracks at a station, etc.

In Germany, before the introduction of electricity into railroad operation, masts with semaphores (or other signals) were so erected along the line that they could be seen from one another, and the signal of the departure of a train from a station was given from mast to mast to the following station. The semaphore, inclining obliquely upward, at the same time indicated to the engineer that his train was expected. As the location of the signals was generally chosen at crossings and other more or less dangerous points, this system afforded great safety, but required, on the other hand, a great many employees.

The numerous interruptions which this system of optical telegraphy was subject to on account of fog and bad weather led the German railroad companies very soon to adopt generally the apparatus used for electrical telegraphy—at first, dial apparatus, and very soon, the Morse apparatus. At present, on German railways there are few switchmen who are not familiar with the use of the Morse apparatus, and even many of the laborers are able to receive and send dispatches.

Since trains could then be announced electrically from station to station, signal masts along the line were abandoned, but in place of them an electric apparatus was introduced which announced the approach

of a train to the gate-tenders at important highway crossings and at other dangerous points, as well as to trackmen. This apparatus is the electric alarm of Siemens and Halske. It consists of a bell which can be sounded electrically from a more or less distant point, such as a station or a gate-tender's house. The signals are given either by a single stroke, or certain combinations of strokes, and the striking apparatus is designed accordingly. In Germany, the number of bell signals to be given is small, and the apparatus is, therefore, almost always inserted in an open circuit, and generally operated by magneto-electric apparatus, less frequently by dynamo-electric apparatus. In Austria, on the contrary, at every watchman's cabin on the line, not only simple bell signals are to be given, but other information is to be communicated to station and track employees, and the apparatus is therefore almost always inserted in a closed circuit, in order to avoid the necessity of providing every signal cabin with a source of current. It is thus possible to insert Morse apparatus in the line, which, however, is not impossible when induction apparatus is used. The various bell signals, in the case of a closed circuit, are given by breaking the circuit, for which automatic devices are frequently used.

Bell signals have recently been introduced on the Northern Railway of France, and on the Paris-Lyons-Mediterranean Railway. After the introduction of the electric bell signals, mast signals in Germany, and discs in Austria, were in general only used as distant signals for protecting stations, switches and crossings. The upward inclined arm, or the edge of the disc, or, at night, green light, meant all clear. The horizontal or normal position of the arm, or the full disc, or, at night, red light, meant "stop." This resulted in trains stopping often at a considerable distance away, without rear protection, and without knowledge as to the cause of the stop. Moreover, in case of fog, or bad weather, the engineer might not always be able to stop his train before reaching the signal, in spite of the penalty of dismissal, so that without backing up he would be without signals for his further guidance. This difficulty has been remedied in Germany, and first in Prussia, by placing the mandatory signal nearer the danger point, its position being indicated to an approaching train by a distant signal. The distant signals, which are generally connected automatically with the home signals, are round discs rotating about a vertical or horizontal axis, the disc or green light showing when the home signal is at

danger, and only the edge or white light when the signal is "all clear." Engineers may run by a distant signal at danger, the train being under control so that it can be stopped at the home signal.

Green light is chosen for "danger" at distant signals, because in Germany the rule is strictly adhered to that the engineer shall under no circumstances run by a red signal. Adherence to this rule has led to a peculiar development in the case of the mast signals. As already stated, the simple semaphore, in its normal danger position, is extended horizontally to the right, or, at night, shows red light; while safety is indicated by the arm pointing obliquely upwards to the right, or by green light.

Aside from the fact that in Germany, where trains run right-handed, the engineer is governed by the arm extended towards the right, and that this arm is raised instead of lowered into the all-clear position, this signal agrees entirely with the English semaphore. The case is different, however, at junctions, when it is necessary to place signals for the main and branch lines on one mast. In this case (in Germany) the mast has two or three arms and lanterns, over each other. The lower arms or lanterns are only used when a train is to be diverted from the main line. When the main line signal (upper) is at all clear or at danger, the lower arms are vertical, and show no light. By this arrangement, when the track is blocked, only one red light is visible at night. If the main line is all clear, one green light is shown ; if the first branch is all clear, two green lights, and if the second branch is all clear, three green lights above each other. Red light is never shown when any track is all clear.

These signals give no information as to the direction of the turnout ; and more than three arms are not placed on one mast ; if there are more than three lines, additional masts must be erected.

The English practice regarding the arrangement of several signals on one mast differs therefore from the German in that the English place as many arms or lanterns above each other as there are diverging tracks, and that all of these lights show normally red. Only the one signal governing the all-clear track is placed at safety, or shows green light. While this is contrary to the German rule never to run by a red light, it serves as an excellent guide for the engineer, who (as in the case of the new French "direction signals") can tell at once from the number of arms or lanterns, not only the number of diverging tracks, but which

one is all clear. There is in this method no limit to the number of signals on one mast.

Position of the Signals.—The position of a distant signal, in order that the engineer may recognize it as intended for him, is not a matter of indifference. As a rule it is placed close to the track which it governs, and on the side of the engineer. In general, the signal need not be over 3 to 4 m. above the ground, so that the engineer of an approaching train may be able to see its position distinctly even in the worst weather or the thickest fog.

In France, great importance is attached to the position of the signal, and it is prescribed by the Minister of Commerce that if there should not be sufficient room for a signal between the tracks at the proper point, it is to be placed on an overhead footway.

The distance of a distant signal from the point to be protected depends principally upon the grade of the track, the speed of trains, and the number of brakes applied. In England, the distance has been generally 1 300 to 2 600 ft. (400 to 800 m.); in France, 2 000 to 2 600 ft. (600 to 800 m.). On account of increase in speed of trains without corresponding increase in number of brakes, it has been necessary in France to increase this distance to 3 300 to 4 000 ft. (1 000 to 1 200 m.) or in some cases even to 6 500 ft. (2 000 m.). In Germany, of late, a distance of 2 000 ft. (600 m.) has generally been assumed, in which a train may be stopped, from the point where the signal becomes visible (including time required to apply brakes): and on this basis the number of brakes is varied, according to the grade and the maximum speed.

Home signals are generally placed as near the point of danger as the local conditions admit.

If there is a facing switch at the entrance to a station, it is considered the point of danger, and in Germany the station signal is some 160 ft. (50 m.) beyond. If the track which the signal governs is occasionally used for switching, the danger point is taken as the furthest point so used.

If several parallel lines run into one station, the same number of entrance signals are to be erected side by side, each with its distant signal.

If trains on the same line enter the station by two or three different tracks which are to be designated by signals, the entrance signal mast has correspondingly two or three arms above each other.

Signals for departure from a station are in Germany, as a rule, only used when departing trains have to run over one or several facing switches. The switches and signals being connected, the position of the signal shows the station employees whether the switches are right for the departing train. The position of the starting signal must be such that it is in front of the longest train that it governs.

Starting signals can also be used in order to preserve the distance of a station between trains following each other. If two or more parallel lines lead out of a station in the same direction, the same number of starting signals are arranged side by side in a line at right angles to the tracks. If a track leading out of a station diverges in two or three directions, two or three arms are to be placed over each other on the same mast.

Part III.—The Train Staff System.

Before proceeding to the block system, so important for railroad operation, another mode of operating must be mentioned, which, indeed, requires no signals, but which can be regarded as the precursor of the block system. This is the "train staff" system, which takes its name from the fact that a staff is used, without which no engineer is allowed to run over the section governed by the staff. As in the block system, the road is divided into sections, there being a station at each end of a section. One staff is provided for each section, the different staffs being distinguished in form and color, and frequently having upon them the names of the two end stations of the section. By this system it is impossible for two trains to be on the same section at the same time.

If trains or engines are to follow each other in the same direction before the staff can be brought back, the following plan is followed: The engineer of the first train receives from the station agent a ticket stating that the staff will follow, and at the same time he is shown the train staff for the section. This is done in the case of every train leaving a station in a given direction before a train comes in from the other direction, except the last train, which carries the staff itself.

The box in which the "train tickets" are kept can, as a rule, only be opened with the aid of the corresponding "train staff."

Of course all trains must stop at the stations between sections.

The train staff system is considered in England as the safest method

of operating, even safer than the electric block system. The train staff is therefore not only still in use, but has also been much improved by the introduction of the electric train staff.

The electric train staff system, as used on the London and Northwestern Railway, consists essentially in having within a hollow cast-iron cylinder a number of train staffs of the same shape and color for a certain section of the road. These staffs can only be taken out one by one, through an opening in the top of the cylinder. The opening is electrically locked from the following station. Every train must therefore be announced to the following station. As soon as a staff is taken from the cylinder, electrical communication is broken between the two stations until the staff is placed in the cylinder at the following station, and not till then can the arrival of the train be telegraphed back. It is thus impossible for two trains to be in the same section at the same time.

Part IV.—Block Signaling.

W. F. Cooke's block system.
E. Clark; C. V. Walker; E. Tyer.
Siemens & Halske.
Lartigue, Fesse and Prudhomme's electric semaphore.
Permissive block system. Spagnoletti.
Hall. Union Switch and Signal Company.
American Signal Company.
Black's block signal.
Concluding remarks.

The Block System.—Starting with the idea that every point of a railway was a point of danger which should be protected by signals, W. F. Cooke, in 1842, proposed to divide a road into sections, and to allow only one train or engine in a section and on the same track at the same time. At the ends of the sections there were to be signal stations with semaphore signals, and his idea was that the semaphore at the entrance to a section was to be a distant signal operated from the other end of the section and placed at "all clear" when the section was free. Since, however, a signal could not be operated mechanically from a distance of 2 to 3 miles, he placed needle-telegraph instruments at the ends of the sections, by which the signal operators could communicate

with each other, and thus make sure that a section was clear before allowing a train to enter it.

Cooke applied this system in 1844 on the Eastern Counties Road, but it was given up in consequence of an accident which, however, was not attributed to the system itself. In fact, this so-called "block system" had at first many opponents among the prominent English railway men, on account of the fact that it required several communications between the ends of a section, and so was a source of considerable delay to trains. They contented themselves, therefore, by providing telegraph stations at the entrances to tunnels and at similar dangerous places at which operators were stationed who could control trains and assure safety at these points.

It was soon found necessary, however, to return to Cooke's system, and at the present time the block system is recognized as the greatest safeguard in railway operation. The details of the system, of course, have been much improved since Cooke's day.

Next following Cooke's apparatus was probably ne needle apparatus introduced by Edwin Clarke on the London and Northwestern Railway in 1853 and 1854. As a train approaches a signal station the operator signals to the station in advance by one stroke of a bell, and if the section is clear the operator there by the deflection of the needle to the right, gives the signal "all clear" if no train is in the section. When the train has entered the section, it is announced to the operator at the station in advance by two strokes of the bell, upon which the latter deflects the needle to the left and signals "line blocked," in which position the needle remains until put at "all clear" for a following train. If the circuit is interrupted, as, for instance, if a train is stalled and the conductor cuts the wire, the needle takes a vertical position. The disturbances of the needle due to atmospheric electricity, which were originally felt, are prevented by the use of "Varley's safety needles."

In the meantime, in 1852, C. V. Walker had introduced on the Southeastern Railway a signal system in which trains were signaled by strokes of a hammer upon a bell. Generally, there were but three signals, namely:

One stroke, departure of a train for London (up train).

Two strokes, departure of a train from London (down train).

Three strokes, arrival of a train.

The strokes were caused by pressing a button. Every signal was acknowledged by repeating to the sender. This audible block system was in 1855 perfected by the addition of a visible signal, consisting of a miniature double-armed semaphore framed under glass and hung on the wall of the signal station, and works quickly and reliably. One arm of the semaphore is red and shows the signal received from the adjacent station, while the other is white and shows the signal given from the local station. Two spring keys, one red and one white, connect the circuit with a battery, and serve to give the bell signals and to set the semaphores. Pressing the white key sets the red arm at the adjacent station and the white arm at the local station at "line clear," while at the same time the bell is struck; pressing the key again strikes the bell, but does not affect the semaphores, while pressing the red key brings both arms back to "line blocked." The inventor's object was to devise a signal which should be the counterpart of the outdoor semaphore signals given to trains. With Walker's apparatus the block system was operated with the greatest strictness.

A patent was also granted in 1852 to Tyer for a signal apparatus based on the same ideas as Walker's. The older instruments have a black indicator for arriving trains, and a red indicator for departing trains; while in the newer instruments the signal is given by a miniature semaphone with a red and a white arm. While, however, Walker used two wires, one of which operated the visible and the other the audible signals, Tyer succeeded in giving both signals with one wire, by adding a ringing key and a relay. Tyer's apparatus is specially recommended by the Board of Trade, and to this, as well as to the fact that it requires but one telegraph wire, it owes its extended use on English and also on French railways.

The block signal systems thus far described are not dependent on the corresponding outdoor signals along the line, but are simply telegraphic apparatus which has no relation to the outdoor signals except that they are under the oversight of one and the same watchman.

In Germany, owing to the fact that from the beginning every station had been equipped with telegraph apparatus for announcing trains, the introduction of the block system was less difficult than elsewhere. At present, Morse printing instruments are used almost without exception for this purpose, possessing the advantage of preserving the

messages. For the introduction of the block system it was thus only necessary to abandon the time interval system previously used, and to require trains to follow each other only at a distance of a section. The fact, however, that all previous block systems were open to the objection that the signals received by the signal operator had to be transferred by him to the outdoor signals, led Chief Engineer Frischen, of the firm of Siemens & Halske, in Berlin, to devise a block signal apparatus in which the outdoor signal was interlocked with the block apparatus in such a way that it was impossible for the operator to set an outdoor signal at "all clear" as long as the section beyond was blocked. The block signal apparatus consists of a cast-iron box hung on the wall of the signal house, and in which are two small openings in which a white or a red disc is visible, the former signifying "all clear," the latter "stop." Under the openings are arrows showing the directions to which the openings refer. Beneath is the mechanism for setting the outdoor signal. "All clear" is shown by a white disc, and "line blocked" by a red disc. The discs are operated by means of signal keys, besides, which, however, there are so-called ringing keys, for indicating by an alarm the approach of a train. The current is generated by a Siemens' machine giving an alternating current for operating the block signals, but which is also suitable for giving the continuous current necessary for the alarm. The alarm, as well as the block signals, require but one line wire for both directions.

Every change in the position of the block signal disc is accompanied by an alarm inside the cast-iron box, while the approach of a train is indicated to the signal tender, both audibly and visibly, by an alarm provided with a disc signal, so that he may at the proper time set his track signal to "all clear." The alarm may also be used to communicate various other signals.

The locking of the signal lever is effected by a lock pressed upward by a spring under the signal key.

Each pair of block signals connected by a wire are then so arranged that they must always give opposite indications. A signal-man who causes the white disc to appear at the station behind him, and thus unblocks the section changes his own disc to red, and thus blocks himself. He cannot send back the current necessary to unblock the section till he has set his out-door signal at danger, and after unblocking the rear section he cannot set his out-door signal to "all clear"

until the following section is unblocked by signal to him from the station in advance.

Since each change of a block signal requires 21 alternating currents, these signals are completely independent of the effects of atmospheric electricity. Moreover the use of the induction apparatus overcomes all the difficulties connected with the use of batteries, so that the Siemens and Halske block system apparatus may rightly be called the most complete and reliable of its kind.

A peculiar block signal was proposed by Lartige, Fesse, and Prudhomme, which has been used since 1874, at first on the Northern Railway of France, and afterward, on the other French railways. It consists of a signal mast carrying at the top two signal arms, one for each direction; these arms carrying also the lenses for the night signals, one red and one green. The green glass is added in order to distinguish the red light of this signal from that of the disc signals. All the glasses are illuminated by a single lantern, the red glass by direct light, the green by reflected light. Each mast carries also half way up two small arms painted yellow, which are not for the engineer, but only for the information of the signal operator. At the foot of the mast are fastened boxes, two for each direction, containing the operating mechanism and alarms, each box being numbered and showing also the track which it governs. The peculiarity of the apparatus consists in the fact that the signal-man himself directly places the arm at the preceding station in the all-clear position. Each signal is also provided with a distant signal, a round or square disc, so that a train may, if necessary, be stopped at the home signal, thus protecting a train standing at that point. The distant signals are operated by hand. If the two sections on either side of a signal mast are clear of trains, all the signal arms hang vertically, in conformity with the French rule that no signal is shown if the track is clear. Boxes No. 1 show behind little openings white discs with the notice—

$$\text{Track } \left\{ \begin{matrix} \text{I} \\ \text{II} \end{matrix} \right\} \text{ all clear towards} \ldots\ldots\ldots\ldots\ldots\ldots$$

Boxes No. 2 also show the white discs, with the following notice:

$$\text{Track } \left\{ \begin{matrix} \text{I} \\ \text{II} \end{matrix} \right\} \text{ open to} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

If a train or locomotive approaches a block station, the signal-man first covers it by the distant signal. As soon as it has passed the signal mast the operator goes to box No. 1 for the track on which the

train is running, and makes about half a revolution of the crank. This sets the corresponding signal arm horizontal, and at the same time the alarm is sounded at the station in advance; the small arm at this station takes the horizontal position, and in box No. 2, connected with it, the red disc is shown with the notice—

Track { I / II } closed to.....

The rear station receives at once the acknowledgment of the signal by the stroke of a bell, and the appearance of a yellow disc with the words—

Track { I / II } train announced at.....

As soon as the signal-man at a station at which the approach of a train has been thus announced by the appearance of the small arm sees that the train has passed his distant signal, he places the latter at danger. As soon as the train has passed he protects it by the danger signal, and by means of the crank in box No. 2 he drops the small arm at his own station, and the main block signal at the preceding station.

Permissive Block System.—In this system a horizontal position of a semaphore commands an immediate stop. If an engineer stops his train, however, and the all-clear signal is not given from the advance station within five minutes, the operator can allow the train to enter the blocked section. The engineer, however, must make sure, by observing the track closely that he incurs no danger, and must proceed so slowly that he is able to stop his train in safety should any obstruction appear. He can resume the ordinary speed only after passing an "all-clear" signal.

Spagnoletti, the telegraph inspector of the Great Northern Railway, has constructed an apparatus in which the signals are given according to the principles usual in England. For each direction there are two indoor signals, the upper showing the signal received and the lower showing the signal given. Instead of dials or miniature semaphores, however, the upper opening shows in its normal position a red disc with the words "lock on," meaning that the signal is locked, while the lower opening shows a green disc with the words "train arrived." The operator inquires of the following station by means of bell signals whether the line is clear and if this is the case the operator there replies by pressing a key which shows at his own lower signal

and at the upper signal of the preceding station a white disc with the words "line clear," and at the same time the track signal at the latter station is unlocked, so that it can be placed at safety. This is done by pulling a lever. As soon as the train has passed, the lever is returned to its former position, covering the train by the danger signal: this, however, not only locks the lever, but shows on the upper opening of its own station and the lower of the following station a red disc marked "train on line." In this position neither of the two operators can alter any signal, since the rear outdoor signal, by being placed at danger, breaks the circuit; so that it cannot be placed at safety, thus admitting a following train to the section. The circuit remains open until the train reaches the following station, when it closes the circuit by means of a track instrument, and at the same time shows at this station in the lower indoor opening a green disc with the words "train arrived," and in the upper opening at the preceding station a red disc with the works "lock on." The operation can then be repeated. Only one line wire is required for this system, including the bell signals, and the details are so arranged that any interruption in the line or any failure of any part of the system brings the signals to the danger position.

This method forms the transition to the automatic block systems. In general, the sentiment in England and the rest of Europe has not been particularly favorable to automatic systems which dispense entirely with manual aid, principally because such systems themselves require in any case continual supervision, in order to ensure their reliable action.

In the case of Spagnoletti's apparatus just described, the signal "train arrived" is operated by the first wheel passing over the track instrument, and it may therefore happen that a train may set this signal and yet come to a stop before it has completely passed the track lever. To avoid the danger which might result, each operator is required to satisfy himself particularly on this point before giving the "all-clear" signal to the preceding station.

Automatic Block Systems.—Although in Europe we have hesitated, thus far, to introduce entirely automatic block systems, in America they have been introduced without hesitation and apparently with good results. Hall was the first to introduce such a signal, which in its newest and much improved form has been extensively used on the

New York, New Haven and Hartford, the Boston and Albany, and other roads. The signal itself is held in its normal position by an electro-magnet in a closed circuit. If the circuit is broken, the disc falls and shows red. Distant signals are similar to home signals except that the disc is green. The breaking of the current is effected by means of a wire circuit with a weak current, in which a second electro-magnet and two track instruments are inserted. One track instrument, the so-called "block" instrument, is at the entrance of a block section and is connected in circuit with the battery at the other end of the section and with the electro-magnet. When the first wheel of a train passes over this instrument, it breaks the circuit and both armatures fall, the signal going to danger.

Some 1 500 to 2 000 ft. (450 to 600 m.) beyond the end of the block section is the "all-clear" instrument, which differs from the stop instrument in that its normal position corresponds to open circuit, and that when struck by a wheel, instead of changing its position at once, it does so only after a time sufficient to allow the passage of the longest train at the slowest speed, by means of a compressed air cushion.* This instrument closes the circuit again and clears the section.

The "block" instrument of any section is beyond the "clear" instrument of the preceding section, so that a train entering a section is protected before the signal at the entrance of the preceding section is cleared.

The compressed air cushion of the "clear" instrument is said to be the weakest point in this block system. Any failure in the current or crossing of wires brings the signal at once to danger. Breaking apart of trains and breakage of rails are not shown by the system, but this could be effected by using the rails as conductors. This, however, is not recommended, since the rail circuits for considerable distances do not operate uniformly and reliably enough. In general, however, the use of the Hall system is strongly recommended, and is particularly suitable for long block sections.

Very similar in working is the electric automatic block system of the Union Switch and Signal Company, in Pittsburgh. The sections are from 1 000 to 1 500 ft. (300 to 750 m.) long, and at the ends are signal masts. At the top of each mast is the home signal, the normal posi-

* This does not quite correspond with the instrument as now constructed.—*Trans.*

tion of the arm being horizontal, or at danger, or at night showing a red light. With short block sections and frequent trains, there is also a distant signal arm for the second section ahead, the end of this arm being notched, as in the English distant signals, to distinguish it from the local home signal. The lantern of the distant signal is normally green, indicating caution, while both signals show white light when at safety.

The signal arms are moved by compressed air, as already stated, controlled by electricity. While the Hall system uses a separate wire for this purpose, the Union Switch and Signal Company uses the rails for conductors. The rails are electrically connected, except at the end of a block section, where there is an insulating joint. It has been found unnecessary to insulate the rails from the ties. A battery at the farther end of the section sends a weak current through the rails, which, at the near end of the section, are connected by the two wires of the electro-magnet which operates the signal. Any pair of wheels in the section short-circuits the current, the armature of the signal electro-magnet drops, and the signal goes to danger, the corresponding distant signal going to "caution." By a switch on the arm of the local signal, the distant signal for the section in advance goes at the same time to caution, while its corresponding home signal remains at safety. Any failure of any part of the apparatus results in the corresponding signals all going to danger. Breaking apart of trains and fractures of rails are at once indicated. If there are switches in the section which are included properly in the circuit, the block signal will only indicate "all-clear" when the switch is properly set and no wheels are upon it.

The method of operating signals by means of bellows, introduced by the American Pneumatic Signal Company, has also been applied to the operation of automatic block signals in a manner as ingenious as simple. When a train enters a section the first wheel, by means of a track instrument, acts on the bellows and sets the signal at danger, at the same time clearing the signal in the rear. The bellows is far enough in front of the block signal that the engineer can see the signal go to danger before passing it, and thus know that his train is protected. This, however, has the serious objection that if a train should stop just as the first wheel had passed over the track instrument, it would not be protected at all.

Black, in his block system for the New York elevated roads, has made use of the principle employed in Hall's electric system, namely, that a train must be protected by a forward block signal before the rear block signal is cleared. In Black's system, however, the operation is entirely mechanical. The transmission of the motion by rods requires the block sections to be short, and the signals are therefore only about 1 100 ft. (335 m.) apart. The rods are supported upon rolls between the rails, and are protected by wooden casing against the sun and against disturbance. Powerful track instruments in the form of levers connected with toggles are operated by the wheels, and carry the motion to the rods. Shocks are avoided by inserting strong spiral springs. A train length beyond the signal mast (one engine and five cars) is the first track instrument which sets the danger signal for the section in advance, and just beyond is the second track instrument which clears the signal for the rear section. In consequence of this overlapping, the signal rods are longer than the length of a section, sometimes up to 2 700 ft. (825 m.). In order to provide for the changes of length of such long rods, due to temperature, the oblique slot at the end of the rod, which effects the change of the signal, is lengthened at both ends parallel with the motion.

The capacity of the roads equipped with this block system is very large. The signals being placed 1 100 ft. (335 m.) apart, and the speed of trains 16 to 17 miles per hour (26 to 27.5 km.), it is possible to have trains follow each other at intervals of ¾ of a minute. This simple system is very inexpensive and yet thoroughly reliable. During the three days of the Columbus celebration, October 10th–12th, 1892, the elevated roads of New York carried 2 921 864 passengers; and on October 12th, alone, 1 075 537 passengers.

In one day, on the Third Avenue elevated road, 8.5 miles long (13.6 km.) the traffic amounted to 55 000 car-miles (87 000 car-km.), and 1 200 engine-miles (19 000 engine km.).

Closing Remarks.—On main lines the block system is now indispensable for safe operation. The choice of a system, however, depends largely upon the character of the traffic. If trains of different length and speed run over the same line, and if the length of stops at the different stations cannot be fixed beforehand with accuracy, the use of the Morse writing telegraph is to be recommended, especially because it preserves permanently the dispatches sent, and thus affords a basis

for providing for further irregularities in time. An interval of five minutes or less between trains is only possible when trains run with nearly the same speed. In such cases the use of writing instruments takes too much time, and it is necessary to resort to methods such as have been described, by which trains are signaled quickly, or to automatic systems.

Part V.—Interlocking Apparatus.

Introduction.

English interlocking apparatus. Saxby & Farmer.

German interlocking apparatus. Max Jüdel & Co.; Rüppel's system; Büssing's patent; Schnabel & Henning.

Fundamental principles of German interlocking. Locking the route; locking apparatus; protection of isolated switches; slotted signal.

Differences between English and German interlocking apparatus. Switch locking; significance of the distant signal; safety switches; detector bars.

American interlocking apparatus. Saxby & Farmer; St. Louis Bridge and Tunnel Co.; Westinghouse's switch and signal interlocking.

Hydraulic pressure apparatus. Bianchi & Servettaz; Haniel & Lueg.

Closing remarks.

Introduction.—The danger which arises from the fact that at a turnout the signal may not agree with the position of the corresponding switches led the English roads, as early as 1846, to concentrate at one point (by means of rods, etc.) the levers operating the switches and signals, so that they could all be operated by one man. Since, even by this method, however, mistakes were not impossible, Saxby, in 1856, conceived the idea of interlocking the switches and signals in such a way that it would be impossible for the operator to set a switch contrary to the signals, or to clear simultaneously two interfering tracks. This idea led to the development of what is known as the interlocking system. According to this system, as soon as (or before) a given lever is thrown, the motion of certain other levers is rendered mechanically impossible. This is effected by adding to the simple lever apparatus a special device, consisting in the main of a movable locking bar,

moving parallel to the row of levers, and provided with the necessary locking pieces. The mechanism is designed on the basis of a given mode of operating the tracks, and a corresponding locking table is prepared, showing positions of the switches and signals which are incompatible or dangerous. The locking pieces are then arranged so as to conform to this table.

This interlocking system has since been found indispensable in governing the entrance and departure of trains at stations where the traffic is heavy.

English Interlocking Apparatus, Saxby & Farmer.—The interlocking apparatus of Saxby & Farmer is distinguished by its simplicity and its solid construction, and it is sufficient in general for English requirements. Its use is limited by the legal requirement in England that facing and trailing switches shall not be operated by means of rods at greater distances than 540 ft. (165 m.) and 900 ft. (275 m.), respectively. In consequence, the switches operated from one point are concentrated within a space which can be easily overseen and watched from the central point. This area is protected in all directions by signals, resembling a citadel, in which the operator—a reliable man, trained from youth by many years' service—holds absolute command. This method has been entirely satisfactory on English roads. Attention has since been directed to a feature which this system does not possess, namely, the interdependence of the interlocking system with the block system.

German Interlocking Systems.—In Germany less reliance is placed upon the signal-man stationed at the towers, since, notwithstanding the interlocking of the switches and signals, he can give an improper or unaccustomed signal to an expected train, and thus bring it in upon a wrong track, where the station employees do not want it, or can allow it to enter before the station-master is ready for it. The Saxby & Farmer apparatus, therefore, which was introduced in Germany in 1870, did not fully satisfy the needs of German roads. The firm Max Jüdel & Co., in Brunswick, builders of railway signal apparatus, at first imitated the English interlocking apparatus, but finally their eminent engineer, H. Büssing, developed it to conform to German requirements. At present this company builds interlocking apparatus after Rüppel's system and Büssings' patents.

In 1874, Th. Henning of the firm of Schnabel & Henning, at Bruch-

sal, showed at the Vienna Exposition an interlocking apparatus of his own construction, and since that time these two and some other German firms have taken the greatest pains to bring their interlocking apparatus to the highest possible degree of perfection.

Fundamental Principles for German Interlocking.—In consequence of the fact that the management of the traffic is separated from the duties of the operator in charge of the levers, and in order that the station-master, who oversees this traffic, may have exclusive control of the entrance and departure of trains at the station, special interlocking devices are applied between the offices of the station-master and the various interlocking towers of the station, which are known as "station blocks" (*Stationsblockwerke*), "signal locks" (*Signal Verschlusswerke*), "electric slot apparatus," etc.

These appliances led to the idea of making the station-master and the signal-operator interdependent, in such a way that before the passage of a train by a tower—

(1) The switches to be passed over must be set and blocked by the operator.

(2) The signal for the train must be cleared by the station-master.

And after the train has passed—

(3) The signal must be put at "danger" behind the train, by the operator.

(4) The switches must be freed for other operations by the station-master. This cannot be done till the train has completely left the protected area.

Locking the Route.—A further innovation in German interlocking is locking the entire route of a train through a yard. Formerly, if a signal was cleared it locked the switch to be passed over in the proper position. This had the objectionable feature that as soon as the signal was put back at danger, the switch was unlocked ; while it is often very desirable that after the signal is put at danger, behind a train, the safe position of all the switches to be passed should be assured till it is certain that the train has passed them all. This led to the introduction of "route levers" which are properly interlocked. This renders it unnecessary to hold the signal lever in the "all-clear" position, in order to lock the switches. On the contrary, all the switches over which the signal gives right of way are locked by the station locking apparatus, without making it impossible for the

operator at the tower to throw the signal to "danger" at any time.

Electrical apparatus was formerly exclusively employed for controlling the levers in the towers at the ends of the station from the offices of the station-master. Lately, however, these have been largely replaced by mechanical apparatus, and electrical locks only retained in connection with such sections as are equipped with Siemens & Halske block apparatus, or in cases where the station is a considerable distance from the levers.

In the newer mechanical locks, double wires are invariably used, which, besides being all that could be desired with respect to simplicity of construction and ease of repair, are, moreover, as a rule, cheaper than electrical locks up to distances of about 4 000 ft. (1 200 m.).

Locking Apparatus.—The locking apparatus in the station (or sometimes on the platform) is operated generally by a crank. Each crank serves for controlling two directions or routes, being connected with a locking bar in the interlocking tower. When the crank is in the intermediate position, this bar cannot be moved; if the crank is turned to the left, it frees the locking rod for one route (*i. e.*, allows the all-clear signal to be given for this route, and locks all switches which the train is to pass over); if turned to the right, it frees another route. This differs from former arrangements in that here it is not the signal lever which is freed or locked, but only the locking bar or the lever by which the latter is moved. Whenever the station crank is turned, the signal operator is informed by an audible and a visible signal, and he is thus directed to clear or to block some given route.

The interdependence already existing between the various levers of the interlocking apparatus of the tower is generally repeated in the locking apparatus at the station, so that the station-master can never free two interfering routes. A further interlocking has also been added such that when the signal has been given for a train to enter by any given track, it is impossible to again give the all-clear signals for that track from any direction whatever until a departure signal for this track has been given and then removed.

Protection of Isolated Switches.—A road is not always in a position to protect a station or junction by erecting at once a special interlocking plant. According to the laws governing the operation of main lines

in Germany, however, signals for the protection of switches, which in ordinary operation are facing points, are obligatory. The signals must be so arranged that the signal for any track cannot be cleared until the switch is set for that track, and the switch must remain so set as long as the signal is clear. Here, also, the object has been to relieve the switchman of the duty of setting the signal, placing this in charge of the station-master. For this purpose, switch-lock discs are used, which are inserted in the double wire by means of which the station-master from his office or from the station platform sets the entrance signal for the station. The disc has a widened rim by means of which either directly or by an intermediate latch, it engages in recesses of a locking bar connected with the switch lever in such a way that the switch can be set at will as long as the signal is at "stop," while the signal can be cleared only when the switch is set for the proper track. Setting the signal at "all-clear" locks the switch in this position.

Slotted Signal.—Even before it was proposed to interlock switches and signals, a device had been introduced in England by which a signal could be cleared only by the concordant action of two signal-men stationed at different points. This device is found principally in cases where signal towers are only a short distance apart, so as to make, for instance, the departure of a train from the area governed by one tower dependent upon permission given from the following tower. The device consists principally in having one or more slots in the rod which works the signal, in each of which slots a pivoted lever works, each lever holding the signal at danger by means of a counterweight. The signal can be cleared only when all the counterweights are raised; as soon as one counterweight falls, the signal goes at once to danger. It is thought that Saxby first conceived his idea of interlocking from this apparatus.

Saxby & Farmer afterwards constructed an apparatus on which the more distant signal-man controls the signal electrically. This is called the "electric slot signal," although in this case there is no slot.

In Germany, slot signals are now used quite widely, in order to secure interdependence between groups of switches operated from different points, with respect to certain switches and signals. By such means all the switches for a certain route operated from one point can be locked, and at the same time the all-clear signal for this route given in the adjoining section.

Differences between English and German Interlocking Apparatus.—In England, as already stated, the signal-men in the towers are quite independent, while in Germany they only do the bidding of the station-master. It cannot be denied that the idea of concentrating the entire superintendence of the traffic in the hands of a capable official appears very desirable, but it must be acknowledged that if the duties of the official confine him to an office in the station building or to a particular place on the platform, he cannot always himself see the condition of things at the ends of the station or yard before giving orders for the entrance or departure of a train. He must therefore rely more or less on information given him by signal-men at those points. The signal-man, as soon as he receives from the station the order to give a certain signal, must satisfy himself that the route to be followed by the train is really clear before obeying the order. Now, since the obstacles in the way of a train are generally about the switches at the end to the station yard, it follows that the most important point for insuring the safety of station service is not at the center of the station, but at its ends. Moreover, mistakes on the part of the station-master, or misunderstanding on the part of the signal-man, are not impossible, even with the most perfect system, and have been the cause of accidents.

If the work to be done daily at a station equipped with interlocking apparatus is laid out systematically and permanently, and the traffic is regular, the signal operator, if he follows the schedule, cannot well open a route that is not desired by the station-master, and even if he should by mistake do so, the engineer of an approaching train would be able to tell from the signals that his own track was not clear and would come to a stop. The danger that a signal-man might allow a train to enter a track already occupied may be easily obviated by arranging the main tracks in the station so that that they form a block section, like the main line beyond the station. No train will then be allowed to enter the block section within the station till the previous train has left this section and its rear signal has passed the further tower.

Finally, it must be acknowledged that if trains follow each other at short intervals, delays will be occasioned, if it is necessary, before admitting them for the signal-man to communicate with the station, so that it is better to concentrate the responsibility in the hands of the

signal-man. A simple telegraph connection is sufficient to communicate special messages from the station-master to the signal-man.

An objection frequently urged in Germany against the Saxby & Farmer apparatus is the large number of levers used. When we remember that, for instance, Max Jüdel & Co. build interlocking apparatus in which a station at the crossing of two double track roads with two switches, two double armed entrance signals, besides two distant signals and four starting signals, are operated by only four cranks (wires being used to throw the switches), it seems worth while to examine the causes for the large number of levers in English interlocking apparatus.

Switch Locking.—In this examination the first striking point is the locking of each switch by a special lever. In England it is considered absolutely necessary to ensure the full contact of the tongue of a facing switch with the fixed rail by means of a special slightly wedge-shaped bolt which is forced into a corresponding hole in the rod connecting the two movable points. The lever of this lock takes the place of the switch lever in the interlocking apparatus. This lock is also generally provided with a detector bar, which prevents the lock from being withdrawn as long as a wheel is over this bar. This doubles at once the number of switch levers.

In Germany, as already stated, the locking of isolated switches by means of the signal wires is generally introduced, but the locking of switches by means of special wires and levers in the towers is only introduced in exceptional cases. In place of them there are special throwing devices at the switches called "point locks" or "switch locks" which are intended to assure the signal-man that in throwing his switch lever he has actually brought the movable point into perfect contact with the fixed rail. This switch lock is intended to be unaffected by small temperature changes of length in the lead-out, or by the unavoidable lost motion occurring to a greater or less extent in the transmission mechanism. These devices, which throw the switch and at the same time lock it in its new position, have thus far proved thoroughly satisfactory. It must be remarked, however, that almost all the interlocking systems in Germany are of recent date, and that consequently the natural wear of bolt connections and other transmission mechanism has not yet taken place to a serious extent. This wear, however, may take place unnoticed to such an extent that if a

slight resistance is offered to the throwing of a switch, it may be possible to throw the lever completely over without ensuring perfect contact of tongue and fixed rail. It must be further recognized that the lateral pressure of cars passing over a switch may gradually result in the point not being in contact. Attention is therefore now being directed to the idea of providing some means, independent of the switch-throwing apparatus, by which the signal-man may be assured that in distant switches close contact is secured.

Significance of the Distant Signal.—Another circumstance which leads to again doubling the number of levers in English apparatus, is the different meaning of the distant signal. In Germany, the distant signal simply calls attention to the position of the home signal, and as both must always be in the same position, they may be operated by the same wire. In England, on the contrary, the distant signal is an independent stop signal, under whose protection, if at danger, the train proceeds. If the home signal is then cleared, the distant signal remains at danger, and not only protects the train against a rear collision, but also locks the proper switches. The interlocking of the distant and home signals is such that though the latter may be cleared, while the former is at danger, the reverse can never occur.

In Germany it is considered unnecessary to protect a train by the distant signal, but dependence is placed upon a strict adherence to the block system. There have been instances, however, of more or less serious rear collisions between a train stopping before the home signal and a following train.

Safety Switches.—The fact that special switch locks are not used in interlocking has enabled German engineers to make the switches so that they can be run over as trailing switches even when set for the wrong track (so-called "safety switches"), without injuring the interlocking apparatus or causing the tongues to assume an intermediate position, clear of both fixed rails. This is effected by making the switch rod connecting the points discontinuous and using the "point lock" already referred to. When a switch is thrown, the operation is as follows: the motion of the rod first moves the point which is not in contact, at the same time unlocking the other point; both points then move together till the former comes to contact, when it is locked, while the motion of the other point continues. If the switch is run through trailing, when wrongly set, the motion is caused by the free

point being forced aside and is transmitted by the rod, the procedure being the same as just described. In order that the interlocking apparatus may not be injured, a connection is introduced between the lever and the switch rod, which is rigid when the switch is thrown in the usual way, but which becomes detached with slight resistance when the switch is run through backward. At the same time the proper signals are locked and the signal-man notified.

Detector bars, which prevent a switch from being thrown while a train is upon it, are seldom used in Germany, the position of the switch being considered sufficiently assured by the locking of the signal lever or of the switch lock lever. It does, however, excellent service if suitably constructed, in all movements which must be made within the interlocked area without requiring or perhaps permitting the operation of a signal or route lever.

American Interlocking.—The Saxby & Farmer apparatus was introduced in America in 1873, and used with it, the English method of operation, consisting principally in separating the announcing from the despatching of trains, this method having been in general and very extended use in America before the introduction of interlocking.

The Saxby & Farmer apparatus is still in use at many large stations, junctions and crossings, but the practical American mind has introduced many simplifications, consisting mainly in placing movable pieces on the locking bolts, which effect a certain interdependence between special locks, and preserve this relation in different positions of the locks.

The considerable force necessary to throw switches by means of rods (pipes) or wires, and the necessity of having a number of signalmen in the towers at the same time, led the Americans to replace manual power, so far as possible, by other forces, mainly hydraulic pressure and compressed air.

The attempt was made on a large scale in 1883, to employ hydraulic pressure for operating the extended plant of the St. Louis Bridge and Tunnel Company. This system covered a length of nearly 3 miles (4.5 km.) of double track, with three towers and about 28 miles (45 km.) of yard and side tracks, with a corresponding number of switches and signals, and operated, in 1887, 131 trains daily. The experiment did not lead to the expected results, and the plant was altered by substituting compressed air as the power, using hydraulic pressure only to

operate the valves. This new plant, designed by Mr. Wuerpel, offers many points of interest. It is described in the *Railroad Gazette*, 1889, page 90. The three towers contain together 108 levers, of which 80 are in the tower at East St. Louis. These levers operate 138 switches and signals. The comparatively small number of levers is due to the fact that by a special device certain signals (as many as nine) can be operated by one lever. This is effected by placing valves in the water pipes leading from the tower to the signal cylinders. These valves are so connected with the switch mechanism that when the signal lever is thrown, the water is always admitted to the signal cylinder which corresponds to the switch in question. The operation of this plant requires the minimum of force. In the East St. Louis tower, one man operates the 80 levers, in eight-hour shifts. The track movements, when completed, are electrically announced at the tower and indicated on a miniature plan of the yard, with movable switches whose positions correspond with those of the actual switches. The electrical contact is made at the point of the switch. The entire apparatus, except that for operating the indicator, is contained in underground conduits and thus protected from injury in case of derailment.

The Union Switch and Signal Company.—By a great expenditure of money, time and labor, this company has succeeded in constructing an interlocking system after the ideas of Westinghouse, which satisfies in the highest degree all the requirements which can be be made upon a safety interlocking apparatus. Its operation, especially, requires little power, it is very compact, convenient in arrangement, and the lead-outs can be placed underground or in any way desired, if necessary outside the track area. The plant is costly, however, and therefore only suitable for large installations. An illustrated description may be found in the *Scientific American* for May, 1891, page 273. The signals and switches are operated by compressed air at a pressure of not less than 2.8 atmospheres. The valves at the switches are operated by hydraulic pressure, those at the signals by electricity. The throwing apparatus, instead of the usual levers and rods, consists of a series of horizontal shafts in a horizontal plane, which are rotated by cranks. The motion of the shafts is limited by electric stops. At the ends of the switch shafts, are three way cocks through which passes the water which operates the air valves at the switches ; while from the ends of the signal shafts, the electric current is sent to operate the air valves at

the signals. Each switch is thrown by means of a compressed-air cylinder, whose piston, in being thrown, first unlocks the switch, then throws it and then locks it again by a locking bolt. Connected with the apparatus is a fouling bar, to prevent the switch from being thrown under a train. The locking bolt, when in its final position, closes a circuit which in the tower effects the release of the lock of the switch shaft. The locking of a signal shaft is effected by a current, which is broken as long as the signal arm is in the all-clear position. The interlocking apparatus in the tower is peculiar. The shafts which serve to throw the switches and signals are insulated by rubber coverings, upon which are strips of platinum, and between the shafts are springs for closing the circuits, so arranged that the sending of the current for a given signal is made dependent upon the previous proper setting of all the switches involved. Throwing any switch out of position would break the circuit and bring the signal to danger. When a signal is cleared, the cranks of all the switch shafts involved are mechanically locked by a special locking bar. Before the signalman is a model of the yard, with movable switches which follow the motions of the actual switches as soon as the latter are fully thrown. Track circuits are also arranged, by which the operator can see which tracks, if any, are occupied by cars. Little covered windows with the number of the route, together with an electric bell, announce automatically the approach of each train, as well as the route which it takes.

Bianchi & Servettaz.—Notwithstanding the unfavorable results attained in America with the use of hydraulic pressure for operating the switches, Messrs. Bianchi & Servettaz have recently brought forward a signal system which they have tried on the Italian Mediterranean road, and which has also been introduced tentatively in Germany by the firm Haniel & Lueg, in Düsseldorf. In order to prevent freezing, the water is mixed with 40% of glycerine, and is used under a pressure of 50 to 60 atmospheres. The pressure serves not alone for transmitting the power, but also for effecting return signals from the tongue of the switch to the operating lever. This not only informs the operator accurately of the position of the switch at any time, and of its movement when being thrown, but is arranged to prevent him from clearing a route for which the switches are not all properly set.

While in the Italian interlocking apparatus the switches are firmly locked in position when thrown, the above-named German firm has made them as safety switches, so that they may be run through trailing, even when set for the wrong track. These safety switches differ in their action from those previously described in one important respect, viz., that, after being run through the points they again assume their former correct position instead of being thrown over. This system has yet to be exposed to the test of practical operation.

Concluding Remarks.—According to the report of Messrs. F. Büte and von Borries, who were commissioned in the spring of 1891 by the Minister of Public Works to make a tour of inspection in America, these engineers saw at the Jersey City Station of the Pennsylvania Railroad three passenger trains leave the train house almost at the same time and proceed on the same track within 1¼ minutes, each train receiving its complete signals, and safety of operation being completely assured.

If we are to judge of the perfection of an apparatus by its results, we must undoubtedly award the palm to the American interlocking systems, especially that of the Union Switch and Signal Company.

With the English interlocking system it has not been possible to attain a train interval of less than two minutes, on account of the greater power necessitated by the use of rods for transmission; while in Germany this train interval must be considerably increased in consequence of the complicated process of announcing trains.

With regard to the objections to the various methods of leading out, and which in the case of rods (pipes) and wires (besides the changes of length due to variations of temperature) consist particularly in the yielding of some of the intermediate supports, resulting in binding and difficulty of operation, we may here specially direct the attention of railroad engineers to the use of compressed air. As compared with hydraulic pressure, compressed air has the advantage that it may be used at a pressure of only 2.8 atmospheres, while the former requires a pressure of 50 to 60 atmospheres. Moreover, the air may be allowed to escape freely anywhere after being used, while the use of hydraulic pressure requires a special return pipe.

PART VI.—MISCELLANEOUS SIGNALS.

Switch signals in general; Max Jüdel's; Backofen's; Cumming's.

Latowsky's steam alarm.

Drilling or shifting signals in general; drilling clock; French indicators; Hattemer's track describer.

Train signals; bell cord; continuous air brakes; electric train signal of the Eastern Railway of France; Rayl's emergency signal; Griggs' train signal; Pennsylvania Railroad signal.

Signals for help; use of the telegraph line; Austrian signal for help; Siemens & Halske's signal.

Switch Signals.—Since the introduction of interlocking, switch signals have lost much in importance, for the interlocked track signals indicate with certainty to the engineer and others the position of the switches. In Germany, therefore, no steps have been taken of recent years towards securing uniformity in switch signals. By the new signal regulations it is prescribed that switch signals must indicate by day or night, by their form, whether the switch is set for the main track, or for which side. Red and green lights are not to be used for switch signals, unless in special cases they are to serve at the same time as danger or cautionary signals.

These regulations are complied with in the most differing ways. As a rule, the case of the signal lantern forms at the same time the signal, and is connected with the tongue of the switch, so that it turns as the latter moves. The light is enclosed in glass painted white, and the signal presents the same form by day as by night. When the switch is set for the main track, the lantern shows its narrow sides in both directions, while if the switch is set for the turnout it shows its wide sides. In order to show the direction of the turnout, there is either a black arrow in the proper direction on the white sides of the lantern, or else the side of the lantern itself is given such a form as will show the direction.

Although, however, the switch signals have lost in importance as regards train movements, they have retained their full importance as regards shifting or drilling movements. In the latter, particularly, derailments are frequently caused by cars running over a facing switch while it is being thrown and the points are not in contact with either fixed rail. In order to indicate with certainty the contact of the

tongue with the fixed rail, devices have been constructed in which a red surface or light is shown as soon as (or just before) the tongue leaves the fixed rail. The switch may therefore have three distinct positions, viz.: (1) for the main track, (2) intermediate position—danger, and (3) for the turnout.

The firm Max Jüdel & Co., in Brunswick, makes such a signal, in which the lantern is six or eight sided. When set for the main line it presents a white surface or light; in the intermediate position it shows red, and when set for the siding it shows white, with a black arrow.

H. Backofen, of Pesth, proposes a small semaphore with the following three positions of the arm: obliquely upward for the main track, horizontal for danger, obliquely downward for siding. The prolongation of the arm carries glass shades of corresponding colors.

A similar signal, that of Cumming, has been introduced in America by the Pennsylvania Steel Company, except that the arm is vertical when the switch is set for the main track. In this signal the arm takes the horizontal position, or red light is shown when the lever is unlocked preparatory to throwing. When the switch is set for the siding the proper signal appears as soon as it is locked.

Latowsky's Steam Alarm.—The shrill sound of the steam whistle is objectionable and disagreeable, particularly when a railroad runs close to an important road or street, or even upon one, as may be the case with so-called secondary roads. The regulations for secondary roads in Germany prescribe, therefore, that wherever there are unprotected highway crossings at grade, the locomotive must be provided with some other form of alarm.

For this purpose Latowsky has made a steam alarm which is as ingenious as simple. He evidently had in mind the rattling made by the cover of a pot on the fire. Steam enters a vessel through a small orifice, and escapes through a wide opening above which is covered by a rattler, upon which is a hammer. This hammer strikes upon a bell which surrounds the vessel, making 200 to 220 blows per minute, independent of the steam pressure in the boiler; indeed, it strikes more rapidly the lower the pressure. A boiler pressure of two atmospheres is sufficient to work the apparatus. In the newer alarms the steam is conducted through a receiver to the chimney after being used.

Drilling Signals.—In order to direct the signal-men in the signal

towers of large stations as to the drilling movements desired, vocal or hand signals are generally insufficient. Whistling signals, though much used, have proved too annoying to people in the neighborhood, especially near large cities or much-traveled streets, and have had to be partially given up, notwithstanding their suitability. The use of a speaking tube leading from a suitable point in the yard to the signal towers has proved practicable only for short distances. Other means have therefore been brought into use. One of these is the "drilling clock" (Rangiruhr), which has proved satisfactory, and in which communication is made with the signal-man by mechanical means. It consists of two discs, one of which is operated by the man in charge of the shifting, and is conveniently located for him, while the other is in the signal tower. Both discs are graduated and labeled to correspond with the different switching movements, and the disc in the tower also has designated upon it the position of the switches to be set for each movement. The discs are connected by a wire and rotate together, a fixed pointer indicating the desired movement. Sometimes the discs are fixed, and the pointers rotate.

Electrical means of communication have also been used in some devices. Of these, however, the electrical indicators introduced on French roads are said to have proved too fragile and unreliable.

Better results have been attained with the track indicator proposed by Hattemer in Berlin. It consists of a metal case, on the outside of which the numbers of the tracks are placed side by side. Above the row of numbers is a slot covered with glass, in which as many square white discs may appear as there are tracks to be indicated; and between the slot and the track numbers is a row of brass pull-rods projecting from the case. The complete apparatus consists of two of these boxes, electrically connected, one in the signal tower and one within reach of the station-master, or whoever has charge of the drilling. When the station-master wants the switches set for a certain track, he pulls down the corresponding rod in his instrument, whereupon both instruments show the proper square disc. The signal-man, by pulling the corresponding rod in his instrument, causes both discs to disappear.

Train Signals.—Numberless are the signals which have been devised for enabling the passengers or conductor of a train in motion to communicate with the engineer. As these are only to be used in case of emergency, they may be designated emergency signals. The

simplest and most common of these is the continuous bell-cord, one end of which is attached to the bell, whistle, or other alarm on the engine, which can thus be sounded. The bell-cord, however, is not easily reached by passengers, and its use requires a certain amount of strength. It has the advantage that it indicates the breaking apart of the train; but in such case, were the engineer to bring his portion of the train to an immediate stop, a collision with the rear portion might ensue, to prevent which great care would have to be exercised by the engineer and the train hands.

This introduction of continuous air brakes has rendered it possible to do away with the bell-cord, and to place it in the power of any passenger, in case of emergency, to stop the train at once. Since in case of breaking apart of a train, both parts are at once brought to a stop, all the requirements are here met in a most perfect manner. Some little time must elapse, however, before all passenger trains are completely equipped with air brakes, and until then some of the devices hitherto used must be retained.

Among these, the most common appears to be the electric train signal used on the French roads. The locomotive is connected electrically with every car of the train, the battery being placed in the first brakeman's box back of the engine. In the last brakeman's box of the train is a reserve battery with alarm. The alarm on the engine can be rung from each brakeman's post and from each compartment. The train hands communicate short signals with each other by means of press-buttons. For the passengers there is a box from which a button projects. If the button is pulled out, a cam revolves inside the box, the current is closed, and the alarm rings continuously. At the same time, signal arms appear on each side of the car, which hang vertically, and are made to appear by mechanism within the walls separating the compartments, thus indicating the compartment from which the alarm was given. When the alarm has been given, the passenger cannot push back the button into its original position; but when the arms are made invisible by being pushed back into the horizontal position, the cam of the instrument is revolved into a position such that the button can be pressed back.

On Austrian roads the emergency signal of Rayl is recommended for general use. At the head of the train, or at each end, is an alarm, and at each end a battery, the two connected by a circuit, but in

opposite directions. The metallic brake rods, etc., may be used as one part of the circuit. Normally no current passes, but when the two parts of the circuit are connected at any point, a current passes from each battery and the alarm is sounded. The connection is made by revolving a shaft which runs continuously over the tops of the cars, which can be done from within.

Another electric train signal is that of Griggs, used on some of the American roads. This blows a special whistle on the engine, by means of the compressed air from the train brake-pipe.

Finally, we may mention that the Pennsylvania road has introduced instead of the bell-cord a continuous rubber hose under the car body, which is supplied with compressed air at a pressure of little over one atmosphere from the compressed air reservoir. This is connected with the whistle in such a way that, as long as there is pressure in the pipe, the whistle does not sound, but when the train breaks apart or the pressure is released by opening a valve, the whistle sounds until the pressure is restored. Other signals can also be given by this apparatus.

Signals for Help.—If a train meets with an accident and is stalled on the road, it is necessary to send word to the nearest station and get assistance. Such cases are fortunately rare, so that a complete signal system has not been developed. If the stations are not far apart, the quickest and surest way will generally be to send out a messenger, particularly on roads using the block system and where trains follow each other closely. If, on the contrary, the stations are far apart, some roads have placed intermediate telegraph stations at suitably situated section-houses, which are only to be used in case of necessity, and are operated by trackmen. In some cases, also, the existing telegraph line has been arranged so that instruments can be inserted at certain points, the instruments being kept ready for use in case of necessity in the nearest section-house. To carry telegraph instruments for this purpose on trains, however, appears inadvisable, considering that in case of accident the instruments as well as the operator are exposed to danger.

The methods which have been described, however, serve more to send telegrams from intermediate points on the road than to signal. Although special means of giving signals for assistance are not generally provided, the continuous electric block signal apparatus, such as is

found throughout Germany and Austria, offers a means of giving such signals. If, as is generally the case in Austria, the bell signal circuit is operated with a closed circuit, all that is necessary is to provide the intermediate (emergency) stations with current breakers. Each time the circuit is broken, the bell strikes once at each station on the section, so that the desired signal can be given by a certain combination of strokes. For instance, the signal "locomotive wanted," is given by five strokes repeated three times. Five strokes and one stroke, repeated three times, is the call for an engine with workmen. If the key is operated by the hand, inaccuracy may lead to misunderstanding in the case of a signal which derives its meaning, not simply from the number of strokes, but also from their grouping. Many roads, therefore, for signaling of this kind, use automatic keys, operated by the hand or by clockwork, which make such errors impossible.

If the alarm circuit is operated by an induction current, it may be used also for a battery current too weak to operate the alarms, but sufficient for the signals for assistance. Making use of this principle, Siemens & Halske have added to their alarm apparatus a special device by which signals can be given at Morse printing instruments inserted in the circuit at the end stations of the sections. For this purpose an insulated brass disc with depressions along its edge is placed on the axis of the alarm. A contact spring presses on the edge, and the circuit is only closed while the spring passes over a depression. This alternate closing and breaking of the current, as the disc revolves, produces the Morse characters if the depressions on the disc are properly proportioned. The number of signals which can be given is limited by the fact that each signal requires a special disc as well as a special key for bringing the contact spring over the discs and at the same time releasing the alarm. Each disc gives also on the Morse strip, at the station, on either side, the number of the alarm from which the signal is given.

This apparatus works perfectly as long as the alarm is wound up. If it should run down and the contact spring happen to be between two depressions, the circuit would be broken.

If a signal for help is given from any point, an alarm is given at the two neighboring stations, upon which the signal-men at those stations are at once to insert the Morse instrument in the circuit, and take the message. In order that they may have time to do this, the signal key must be held in the alarm which has been released until the latter has

given 42 to 48 strokes of the bell. If the signal has been correctly received at the adjacent stations, one of the latter replies by giving the so-called "alarm signal," which consist of six strokes six times repeated, and which is, of course, produced on all alarms in the circuit. The signal is generally given from the station which has last signaled the train in question. If the alarm signal is not given shortly after the signal for resistance, the latter must be repeated till it is acknowledged. Since, however, while a train is passing a certain section, the telegraph apparatus at the two end stations is closely watched, in order to give or receive notice of the arrival of the train at the further station, the operations involved in giving, receiving, and acknowledging a signal for help generally take place very quickly, seldom requiring more than four minutes.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

623.

(Vol. XXIX.—August, 1893.)

TRANSMISSION OF POWER IN OPERATING CABLE RAILWAYS.

By ROBERT GILLHAM, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The subject of power and power transmission will not be considered in this paper theoretically or mathematically, but in a practical manner. It is proposed to treat of that branch of the subject which relates more particularly to cable street railways.

One cannot enter the central power station of a cable railway system without feeling impressed with the mechanical results secured. Large engines, working day and night and knowing no rest; large rotating gears, whose continued roar tells the story of mechanical work, which is in turn performed by the steel cables which pass out into the street from rapidly moving driving-drums. This activity, these moving gears and drums, the regular click of the engine valves,

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

all tell the interesting story of power generation and power transmission. To those not informed, a scene like that ordinarily presented in an operated cable railway station is bewildering and confusing in the extreme. It commands respect and admiration, and while the result of power generation is invisible, the mind cannot measure, even by comparison, the ever-varying degrees of power developed.

The engineer, at the side of the engine cylinder, with oil-stained overalls, takes a little paper card from a small instrument, the indicator, which tells, in detail and with certainty, much about this question of power. We will, in imagination, visit a few cable power stations, and learn, if possible, something about their arrangement and machinery for power transmission, etc., and, by taking a few indicator cards, try to learn something about the great forces that operate them.

Kansas City, Mo., has, it is said, one of the most complete cable railway systems in the country. Without passing on this point, it may be said that this city is most thoroughly supplied with cable traction. Kansas City is noted for its bluffs and hills, and for this reason the cable railway finds a wide field of usefulness here.

The location covered by the Kansas City Cable Railway Company's Eighth and Ninth Street lines is, no doubt, the most difficult cable railway location to which we can refer. This road was promoted and built by the writer, following the first San Francisco roads. It is considered a pioneer road, and when it was proposed to operate the main cable around right-angle curves, it was considered impracticable by many engineers, and in this case we have the first application of the main cable operating such curves.

Curves were, up to this time, operated by auxiliary cables.

There are two right-angle curves on this line, each of 55-ft. radius. Commencing at the western terminus of the line, at the Union Depot, we find an elevated waiting-room above the street, then a level piece of track for a distance of about 250 ft., then a 19% ascending grade on an elevated steel structure, which extends to the summit of the high bluff, a distance of about 1 000 ft. From the summit a 10% descending grade for a distance of 350 ft. reaches the power station.

The grades from the power station all descend to Main Street, where an ascending grade of 15% occurs for one block, then an ascending grade of 10% for one block, where a right-angle curve is located.

One block from this curve another similar curve occurs. The other grades vary from a level to 8 per cent. It will be seen that the power station is near the western terminus of the road, as well as near the steep incline.

The cable is 22 000 ft. in length, passing from the power station and running to the extreme eastern terminus of the road, then returning to the western terminus at Union Depot; thence by the south conduit to the power station. The length of this division of the road is about 2 miles, double track.

In the power station are two 24 x 48 in. Wright engines, one of which operated the road until the Washington Avenue line was added. The engine shaft has a pinion keyed to it, 6 ft. in diameter, 15-in. face, 5-in. pitch, which drives a large gear on the main-line shaft, 10 ft. in diameter, 15-in. face, 5-in. pitch.

The main-line shaft extends back of the driving drums, on which is arranged a clutch pinion 6 ft. in diameter, 10-in. face, 4-in. pitch, which drives the drum gears arranged on the driving drum shaft; these gears are 10 ft. in diameter, 10-in. face, 4-in. pitch. The intermediate pinion between the drum gear on the intermediate shaft is 5 ft. in diameter, 10-in. face, 4-in. pitch. The cable used is $1\frac{1}{4}$ ins. in diameter, weighing 2.5 lbs. per linear foot, total length 22 000 ft., making a total weight of cable 55 000 lbs. Speed of cable 7.03 miles per hour.

A series of three or four tests were made each month, in order to determine accurately the horse-power developed in performing the work of propelling the cars on the road under varying conditions of traffic and weather. The test began by taking 36 indicator cards on the first day of the test, making two cards each hour during operating hours, which was repeated several times each month, covering a period of about 10 months.

It will be seen by Table No. 2 that the mean power required to propel a grip car and one closed car with passengers, is $4\frac{1}{2}$ H. P. There are no means of determining the passenger load on these trains, but the grip car without passengers weighed 4 800 lbs., and the passenger coach, 4 000 lbs.; these cars constituted a train. The mean number of trains operated during this period was 9.6 trains; the lowest number, 5.6 trains; the highest, 13.2 trains.

Many times when cards were being taken, the local position of

trains was such that a large proportion of them were descending the various grades on the line of railway, and, having contact with the cable compensation was thus secured, and very little power, if any, developed by the engine ; in other words, gravity for a brief period of time performed the work of the engine, when suddenly, the position of the cars on the street having changed, the engine seemed almost instantly to develop high power in propelling the cars.

The mean resistance of the engine and main-line shaft, as developed by these tests, was equal to 16.41 H. P. The lowest resistance noted was 12.24 H. P., and the highest 21.12 H. P. The variation of the resistance of engine and shaft was largely due to the Weston-Capen friction clutch on the main shaft, whose plates must have been slightly in contact, thus producing brake action. These clutches form a part of the pinion on the main shaft, and were used for the purpose of communicating power to the pinion and thence to the driving-drums. One set of these driving-drums usually requires 5 H. P. to operate them, without cable. The mean power developed in operating the cable without cars, machinery and engine was 37.24 H. P.

The total number of indicator cards taken during the tests was 333.

There was a maximum variation of about 5 H. P. in the power required for engine, cable and machinery. This variation was no doubt due to the condition of the road machinery, including the two right-angle curves having defective curve pulleys, poor lubrication and bad weather.

Commencing with Test No. 12, it will be seen that the power increased to a trifle over 42 H. P., an increase of about 14 per cent. This was largely due to changes in the road machinery, principally the carrying sheaves, which were 36 ft. apart, and almost doubled in weight. A valuable lesson in the transmission of power for cable railways can be learned by studying the elements that caused this increase of power.

The carrying pulleys originally used in this road had webs of light corrugated sheet steel, with rims from rolled plate steel, with a groove for the cable, the rim being riveted to the corrugated web, diameter, 22 ins.; weight, 37 lbs.; diameter of journal, $\frac{7}{8}$ in. During the period of the test, a great many of these carrying pulleys were

TABLE No. 1.

Table of Kansas City Cable Railway Tests.

Date.	No. of test.	Size of engine.	Total No. cards taken.	Duration of test, hours.	Average total horse-power.	Horse-power for engine and main shaft.	Horse-power for cable and machinery.	Horse-power for cars and passengers.	Percent. total horse-power to run engine and main shaft.	Percent. total horse-power to run cable and machinery.	Percent. total horse-power to run cars with passengers.	Greatest strain on cable.	Average strain on cable.	Average No. trains run.	No. of engine.	Average horse-power per train.	Remarks.
Aug. 7th, 1891.....	1	24 x 48	36	18.5	72.12	14.09	32.39	25.64	19.54	44.91	35.55	8 350	3 840	5.6	L H.	4.578	Fair weather.
Sept. 8th, "	2	"	30	15.0	95.13	15.78	42.05	37.29	16.59	44.21	39.20	7 027	4 203	8 8	" "	4.226	Curve out of order.
" 22d, "	3	"	32	16.0	94.35	12.75	33.83	47.76	13.52	35.86	50.62	9 850	4 388	9.1	" "	5.248	
Oct. 11th, "	4	"	22	10.5	92.02	16.07	35.82	40.13	17.46	38.93	43.61	5 670	4 312	9.8	" "	4 093	
" 26th, "	5	"	32	16.0	82.40	18.71	35.00	28.69	22 70	42 47	34.82	7 787	4 423	9.2	" "	3.119	
Nov. 10th, "	6	"	34	17.0	95.73	16.00	35.84	43.89	16.71	37.44	45.85	7 840	4 178	9.1	" "	4.822	
" 25th, "	7	"	34	17.0	90.00	21.12	29.76	39.12	23.46	33.07	43 47	9 000	3 700	9.2	" "	4.252	
Dec. 29th, "	8	"	30	15.0	94.78	18.35	36.68	39.75	19 36	38 70	41.94	9 100	4 038	9.5	" "	4.184	Snow, track muddy.
Jan. 14th, 1892.....	9	"	34	17.5	94.57	16.10	36.63	41.84	17.03	38.73	44.24	7 940	4 140	9.2	" "	4.547	Rain and snow.
" 29th, "	10	"	34	17.0	100.52	20.03	30.57	49.98	19.93	30.35	49.72	11 730	4 250	9.2	R.H	5.432	Track muddy.
Mar. 4th, "	11	"	34	17 0	100.13	17.01	35.86	47.26	16.99	35.81	47.20	18 050	4 230	9.2	" "	5.136	
" 5th, "	12	"	34	17.0	99.60	12.23	42.20	45.17	12.28	42 37	45.35	13 670	4 620	9.2	" "	4.909	Track very muddy.
" 24th, "	13	"	34	17.0	104.53	12.23	42 20	50.10	11.70	40.37	47.93	15 000	4 890	10.0	" "	5.010	
May 12th, "	14	"	34	17.0	112.00	18.64	42.21	51.15	16.64	37.69	45.67	17 473	5 900	12.0	" "	4.262	
June 8th, "	15	"	34	17.0	107.73	18 64	42.21	46.88	17.30	39.18	43.52	17 340	5 120	11.8	" "	3.973	Rained.
" 22d, "	16	"	34	17 0	118.80	14.91	42.70	61.19	12.55	35.94	51.51	18 980	6 270	13.2	" "	4.635	
Average.....	....	.....	33.27	16.34	97.21	16.41	37.24	43.41	17.10	38.49	44.39	11 550	4 531	9.63	....	4.526	

removed, and in their places a pulley 22 ins. in diameter, $\frac{7}{8}$ and $1\frac{1}{8}$ in. journal, from cast iron was used, weighing 76 lbs., which resulted in increasing the power required to drive the rope.

The variation of power developed in propelling cable, cars and passengers, as shown by the table, needs no comment; varying loads, conditions and weather, all contribute to the changes shown in this column.

The percentage of total horse-power to operate the engine and main shaft, cable and machinery, cars and passengers, is shown also in Table No. 1. The mean percentage of total power developed and required to overcome resistance and operate the engine and main shaft was 17.11 per cent. The mean percentage of total power developed to operate the cable and machinery was 38 per cent.

The mean percentage of total power developed to propel cars, with passengers, was 44.4%, which leaves 0.45 of 1% unaccounted for, due probably to slight errors.

The tension on the cable was observed to vary, depending directly upon the position of trains and condition of traffic.

The minimum stress on the cable was secured when six trains were operated. The maximum stress, with this number of trains, was 8 350 lbs.; the mean stress, 3 804 lbs.

The maximum stress was observed when 13 trains were operated; with this number of trains the maximum stress was 18 980 lbs.; the mean stress, 6 270 lbs. The stress on the cable is ever changing. If all, or a large proportion, of the cars are descending grades, the stress is low; if on ascending grades, the stress approaches maximum, particularly if this condition arises during hours of maximum travel.

Several extensions were made of this system, and the new Woodland power station was built. There was also another line projected, built and operated from the power station first described, called Washington and Summit Street line, requiring a rope 23 759 ft. in length.

Table No. 3 shows the tests made on the cables operated from Woodland Station, which have, with the exception of Troost Avenue, been extended since the tests were made.

The power station and machinery is, in design, like that described above, in the first station. After numerous tests, the following was adopted as a reliable result. (Table No. 3, page 550.)

TABLE No. 2.

Test of Carrying Pulleys—Kansas City Cable Railways.

Name of Line.	Reference No.	Weight of pulley.	Diameter of pulley.	Diameter of journal.	Ratio of diameters.	Comparative ratios.	Comparative weights.	Length of cable.	Horse-power per 1 000 ft. rope at 7.3 miles per hour.	Horse-power per 1 000 ft. rope at 8 miles per hour.	Horse-power per 1 000 ft. rope at 9.7 miles per hour.
		Pounds.	Inches.	Inches.							
East Ninth Street	1	40	11¾	1¼	1 to 9.4	1.00	1.0	6 202	.....	5 084	5.413
Standard of 1888	2	30	10½	¾	1 " 14.0	1.39	0.75	21 260	3.184	.....	
Independence Avenue	3	76	22	1⅛	1 " 19.5	2.08	1.9	8 571	.....	2.963	3.153
Main Line (old pattern)	4	76	22	⅞	1 " 25.14	2.67	1.9	15 960	2.9		
" (steel)	5	37	22	⅞	1 " 25.14	2.67	0.9	21 000	1.454		
Troost Avenue, 1887	6	.....	.....	.....	.....	.....	.....	33 600	.....	2.906	
" 1888	7	.....	.....	.....	.....	.....	.....	33 600	.....	.....	3.129
Washington Avenue	8	19	16	11/16	1 to 13.27	1.41	0.47	23 759	.....	.....	2.834

TABLE No. 3.

TEST OF CABLES—WOODLAND AVENUE ENGINE-HOUSE—KANSAS CITY CABLE RAILWAY.

ENGINE DIAMETERS.	Horse-power for engine and machinery.	Horse-power for the Independence Avenue rope.	Horse-power for the East Ninth Street rope.	Horse-power for the Troost Avenue rope.	Total horse-power for all.	Speed of engine.	LENGTH OF ROPE.
First tests, 28 x 48 ins.....	34.16	25.4	31.53	96.75	187.84	60	Troost Avenue, 33 600 ft. Independence Avenue, 8 571 ft.
Second tests, 28 x 48 ins...	37.76	26.87	33.57	104.17	202.37	72	East Ninth Street, 6 202 feet.

NOTE.—In this test, cables all taken off the drums and each indicated as put back. Each set of drums required 5 H. P.

The driving drums in both power stations are from cast iron, and are cast solid, with grooves for ropes cast in drums, and carefully turned down. The Woodland Station has the engines arranged end to end, each engine shaft having independent balance wheels and independent pinions, which pinions engage with the same driving gear on the main shaft, one on one side and the other on the other side of the gear. As a result of this arrangement, one pinion drives downward, and the other upward. This is not a desirable arrangement, if it is proposed to work the engines together for any length of time, in operating the cables with their load. Recently it became necessary to impose the additional work of operating the main line on the Woodland Station, in addition to the three roads operated daily from this station. This additional work requires the use of both engines.

The attempt to use both engines was of short duration, as one pinion transmitted power to the main gear downward, and the other on the opposite side of the gear upward. Both pinions, as well as gear, were dry loam castings; neither the pinions nor gear had cut teeth. There were inequalities and slight variations in pitch, due to strains and swells in castings, when they were made. The pinions were not absolutely and theoretically alike, although intended to be

alike, and in the very nature of things could not be, unless they were cut.

The engines and pinions would not work well together, and the disturbance was so great, that, after the fracture of one tooth, the operation of the engines and pinions together was abandoned.

We will now consider the Cleveland City Cable Railway system of which the late Colonel W. H. Paine was constructing engineer, and the writer consulting engineer.

In designing the machinery, it was thought more desirable to connect the engines directly to the main shafts, which is nothing more than an extension of the engine shafts. The main shaft was placed between the driving drums, occupying exactly the same position that the intermediate shafts of the Kansas City cable machinery occupies, and the intermediate gear in the Cleveland case became clutch gears.

The Cleveland engines are Wright automatic engines, 38 x 60 ins., the fly-wheel with each engine weighing 115 000 lbs. Revolutions per minute, 64.

The engines, as stated, are connected with the main shaft, one at each end, the main shaft having a length of 116 ft., and a diameter of 16 ins. The pinions engaging with the drum gears are 5 ft. 1 in. in diameter, 12-in. face, with $4\frac{1}{2}$-in. pitch, which are arranged for plate friction clutches, Weston-Capen type. The gears are cast iron, dry loam castings, and are all 13 ft. 3 ins. diameter, 12-in. face, and $4\frac{1}{2}$-in. pitch. The driving drums are eight in number; the last four are not with their gears, etc., placed in position, the road to be operated by them not having been built. The last set, however, is shown on the drawing, but have not been put in ; those in use vary in diameter, that constant speed of engine may be had and differing speed of ropes secured. One pair of drums is 16 ft. in diameter, one pair 12 ft., and the remaining two pairs are 14 ft. in diameter. The drums have not solid rims, but are provided with renewable and movable steel groove rings known as Walker's patent rings. Each ring, which contains a groove for the cable, is independent of the others, and this allows equalization of stress, when necessary, in the cables around the driving drums. In order to equalize this unequal stress of the cable in the use of solid drums, the rope is compelled to slip in the grooves of the drums. In using the differential rings referred to, the

rope does not slip, but the rings forming the grooves and rim of the drums perform this action, and are kept thoroughly lubricated at the inner side of the ring where contact with the shell of drum is had.

In providing specifications for driving drums, it is the practice to require the diameter of the first groove of solid drums to be slightly larger than the second and third for the reason, as was maintained, that the wear on the first groove would be much greater than on any of the others.

The examinations of a number of solid drums after five or six years of use, have shown a very great reduction in the diameter of the drums, amounting to a reduction from 1 to $1\frac{1}{2}$ ins., due to slip of cable. A majority of the drums examined, however, showed that the greatest wear was in the first groove. This condition of drums naturally resulted in a great waste of power, excessive and unequal stress on the cable and its rapid wear, and early destruction of the drum rim. This, however, caused no serious trouble, as the grooves of the solid drums were turned to relatively the same diameter from time to time, to correct the trouble. The differences in the circumference of drum grooves of varying diameters are much greater than imagined, even though the difference in diameter is small.

12 ft. diameter	37.699	circumference.
$11\frac{7}{8}$ ft. "	37.306	"
Difference	0.393 ft.	

Each section of cable on drums, therefore, in order to maintain equal speeds under these conditions, must slip; if a slip occurs, in addition to the wearing effect upon the grooves of the driving drums and cable, it also acts as a brake to the rotation of the drums, and thus more power is required to drive the cable.

It must be remembered, that in the operation of all cable railways, increased adhesion of the cable to the driving drums is secured by means of a tension car with a large sheave, to which the cable passes from the driving drums, and from which sheave it passes into the street.

Attached to this car, which has a horizontal movement, is a chain

which passes to a deep pit at the remote end of the tension car track, to which is attached heavy tension weights, varying in different cable railways from 3 000 to 7 500 lbs. By the weights acting on the movable car, all slack coming into the station is taken care of, as well as the resistance on the driving drums maintained.

In this power station, crude oil is used for fuel for the generation of steam.

The writer wishes now to point out a few interesting facts relating to the test and computation of power developed in the operation of these cable railways.

TABLE No. 4.

Cleveland City Railway.

Name of Line.	Speed per Hour.	Length of Cable.
West Payne Avenue	12 miles	24 050 ft.
East Payne Avenue	12 "	25 300 "
West Superior Street (changed from 10 to 12 miles per hour)	12 "	24 300 "
East Superior Street	14 "	23 900 "
Water Street (auxiliary cable, driven by West Superior Street cable	4 "	7 850 "

One of the problems in designing this railway was the operation of the cable from the Post Office Park to Water Street, on West Superior Street, where electric cars, horse cars and cable cars are compelled to use the same track, and where the headway of cars, due to the common use of this section of the road, is as low at certain hours as 1½ minutes.

From Superior Street the line follows Water Street to the Union Depot. This difficulty was met by operating this section of the railway by means of an auxiliary cable 7 850 ft. in length, driven by means of auxiliary driving machinery in a vault under Superior Street, at the Post Office. The auxiliary machinery is driven by power taken from the West Superior Street main cable, which runs at a speed of 12 miles per hour, and which, in turn, by the arrangement of the auxiliary machinery, operates the auxiliary cable to the Union Depot at a speed of 4 miles per hour.

TABLE No. 5.

Cleveland City Cable Railway.

(Table Illustrating Brake Action of Friction Clutches.)

Test.	Load.	Indicated horse-power.	Length of cables in ft.	Remarks.
1.....	Engine and line shaft only.	143.65		It will be noticed that the sum of the H. P. of the individual tests of each cable (without cars) is 802.03 H. P., which sum, if correct, would equal the power required to drive all the cables empty. Test No. 6 gives the actual power required to operate all the cables with 30 trains and their load as 509.56 H. P., which is correct, as the clutches, when all thrown in, could not exert brake action. The difference between these amounts is brake action 292.47 H. P. The total brake action in tests for cables only exceeds this amount by the power required for cars.
2....	Engine, line shaft and East Superior Street cable only.	173.51	23 900	
3.....	Engine, line shaft and West Superior Street cable only (auxiliary cable).....	141.50	24 300	
4.....	Engine, line shaft and West Payne Avenue cable only.	158.93	24 050	
5.....	Engine, line shaft and East Payne Avenue cable only.	184.44	25 300	
	Total.....	802.03		
6.....	All cables in operation and 30 trains or 64 cars in operation.....	509.56		
	Difference.....	292.47		

Total power computed from first series of cards, which were taken when all the cables were in operation, including auxiliary and including also engine and shaft resistance, was..... 487.14 H. P.

Total power determined by individual test of cables, by first taking cards for all cables, and then throwing out one cable and indicating the others, and thus testing each cable, in the same manner, without engine and shaft friction, gave as indicated in table..... 354.42 "

Engine and shaft friction, as shown by cards for same. 122.37 "

Total ..... 476.79 "

Power unaccounted for..... 10.35 "

It will be observed that the high-speed cables require much more power per linear foot than the other cables when considered independent of curves.

The cables are all 1¼ ins. in diameter and weigh 2.6 lbs. per linear foot.

The tests illustrating brake action are given for two purposes, one to illustrate the fact that all tests made of cable plants and power developed cannot be relied upon, and also for the purpose of pointing out the elements of error in these tests.

TABLE No. 6.

Cleveland City Cable Railway (Cleveland, Ohio).

Cable No.	Name of Cable.	Length of cables in feet.	Speed of cables in miles per hour.	Horse-power required for cables.	Horse-power required per linear foot of cable.	Remarks.
1.....	East Superior Street.....	23 900	14	78.43	0.00328	Practically no curves on this cable.
2.....	West Superior Street.....	24 300	12	61.25	0.00252	Practically no curves on this cable.
3.....	East Payne Avenue.....	25 300	12	144.13	0.00569	Four right-angle double-track curves.
4.....	West Payne Avenue	24 050	12	56.11	0.00233	No curves on this cable.
5.....	Water Street Auxiliary	7 850	4	14.50	0.00184	One double right-angle curve.

Computations of cards taken for the purpose gave for engine and shaft friction, 122.37 H. P. Total, as given above, 476.79 H. P.

Shortly after the indicator cards were examined, and the computation of power made, the company was notified that one or more of the friction clutches were out of adjustment. Before the difficulty was corrected, on many occasions it was noticed that the West Superior cable clutch, if thrown out temporarily for the purpose of making necessary examination of the cable, would almost instantly become heated, and on several occasions it became so hot that a stream of water from a small hose had to be used to cool it. An examination of the clutch and its movements developed the fact that the horizontal movement of the plates constituting the clutch was not sufficient, and generally left the plates slightly in contact with the fixed plates that rotated with the shaft, when the lever was in a position that should maintain absolute separation of the friction plates. The only means of relief was to take the cable off the driving drums when it needed repairs, throw the clutch in, and operate the empty drums with the rest of the machinery, until the cable had been repaired, when the drums were for a few minutes stopped and the cable replaced on them and again started. These defects were corrected and the clutches properly adjusted.

On another occasion, the tests made to determine the power developed during hours of maximum travel, when compared with the power required to operate empty cables on the same day, developed the fact that the clutches were all more or less acting as brakes on the empty cables tested, the others being idle. This could have no effect upon the work of the engine if all the cables were in operation, but if any one of the cables had been stopped for any purpose, brake action on the rest would immediately take place.

It was discovered that the engineer had not properly lubricated the friction plates of the clutches, which had become gummed up with old oil and which caused the plates of the clutch to adhere to each other. It was found that cards in Test No. 1 (in Table No. 5) gave a mean resistance of 143.65 H. P., and cards in Test No. 3 (in the same table) gave 141.50 H. P. This is more remarkable when it is understood that to the work of the engine as shown on cards in Test No. 1, which are supposed to indicate only the power developed in operating engine and main shaft, all the driving drums and cables remaining idle, there is added the West Superior Street cable, 24 300 ft. in length, driven at 12 miles per hour, and the auxiliary machinery at the Post Office, including its cable, 7 850 ft. in length.

The fact was developed in subsequent tests, that the power required to operate the West Superior Street cable auxiliary machinery and its rope was 75 H. P.

The power test of the Cleveland Cable Railway, illustrated in Table No. 6, is correct, and was made after clutches had been properly adjusted.

It is needless to say that, in many tests, this brake action of clutches has not been noted, and the world is informed that the resistance of cable machinery is too high, and no considerable economy can be secured in the operation of cable railways.

Thus it is errors creep into census bulletins, lectures and papers on the subject of cable traction.

The Denver City Cable Railway system, is, perhaps, the largest single cable plant in the country, that is, there are more miles of cable railway operated from its power station than from any other single power station in the world, which affords a very excellent opportunity of studying the question of power transmission in its relation to cable railways. The writer, in designing this system, concluded to use cotton rope or belt transmission from the engine to the main shaft, and thus do away with the necessity of using cast-iron pinions on the engine shaft, and a large extra gear on the main shaft. In order to operate the entire system from a central power station, it became necessary to secure a certain piece of property, the only remaining available piece being too small in area to attempt the construction of any but a very compact plant. Therefore, rope and belt transmission was not considered in the final design for this machinery.

From the power station there are six cables operated, having the following lengths and speeds:

TABLE No. 7.

DENVER CITY CABLE RAILWAY.

No.	NAME.	SPEED PER HOUR.	DIAMETER.	WEIGHT PER FOOT.	LENGTH.
1.....	Larrimer Street.....	10 miles.	1¼ in.	2.6	23 100 feet.
2.....	Sloan's Lake.....	"	"	"	31 250 "
3.....	Seventeenth Avenue.	"	"	"	31 347 "
4.....	Welton Street.....	"	"	"	36 850 "
5.....	West Denver.	"	"	"	28 000 "
6.....	North Denver.....	"	"	"	25 270 "
			Total lin. ft. over 33 miles.		175 817 "

The engines are automatic cut-off engines, two in number; cylinder, 36 ins. in diameter; stroke, 60 ins.; engine shaft, 20 ins. in diameter; fly-wheel, 20 ft. in diameter, weighing 125 000 lbs. Revolutions per minute, 56.

On the engine shaft, between the engines, are arranged two pinions bolted together side by side, staggered so that the teeth of one alternate with the teeth of the other. The diameter of these pinions is 9 ft. 3 in., each 20-in. face, making a total face of 40 ins.; the pitch, 7½ ins.; total weight, 45 000 lbs.

The gears on the main shaft were 12 ft. 10 in. in diameter, 20-in. face, each staggered like the pinions, making a total face of 40 ins.; pitch, 7½ ins.; total weight, 70 000 lbs.

The large gear was allowed to run in oil at the lower side in the gear pit. The peripheral speed of these large gears was 2 257 ft. per minute.

The pinions on the main shaft engaging with drum gears are all clutch gears, and are 12-in. face, 64½ ins. diameter. The pinions on the intermediate shaft are 5 ft. in diameter, 12-in. face, and 4½-in. pitch. All drum gears are 10 ft. in diameter, 12-in. face, and 4½-in. pitch. The driving drums are 12 ft. in diameter and have six grooves. All pinions and gears are from cast iron, and are dry loam castings, and are not cut gears.

For two years the large engine gears worked very satisfactorily indeed, although, with the heavy work performed, they occasioned considerable noise and jar. Finally, one night, when the engines were about to cease operations, two teeth in one of the large gears broke, but the other gear of 20-in. face was still in perfect condition. The mean horse-power developed during the day was about 800 H. P. The writer advised the operation of the road with the single gear of 20-in. face, as this had ample capacity to transmit the maximum power required for the operation of the cable railway.

This gear ran for several months, when the pinion developed a fracture. New gears were substituted, as well as new pinions; these were made from cast iron, and were not cut gears.

A change was made in the designs and arrangement of these gears and pinions. The pinion is 111.9 ins. diameter, 32-in. face, 8.57-in. pitch. The gear is 152.8 ins. diameter, 32-in. face, 8.57-in. pitch, and were single pinion and gear, and cast in halves, instead of double gears as before.

These operated successfully for a period of seven or eight months, when again during the night, as is reported, the engine frame was fractured, and the rim of the large gear cracked. These injuries were repaired and the road operated as befor

Cast-steel cut gears will soon be substituted for the cast-iron pinions and gears now in use. These will have the same dimensions as the first gears and pinions described ; same weight, same diameter, but a pitch of 6 ins. instead of 7½ ins.

There is no reliable explanation given by the engineers in charge that throws much light on these accidents. One thing can be relied upon, that the power developed in operating the cars and cables is not sufficient to strain the pinions or gears, or cause the fractures referred to. In the operation of the road, no unusual strains occur, imposing sudden destructive shocks on engine and gears. A sudden and irresistible strain must have occurred to occasion these fractures. The cause was not fully determined, but the conclusion was that they might have been occasioned by the following causes :

First.—By water in the engine cylinder.

Second.—By the high speed of gear and irregular gear teeth.

Third.—By inadjustment of the main shaft.

Fourth.—By loose bolts holding the gears together.

Fifth.—By strain in castings, due to forcing halves together.

It was discovered that, during the night of the accident, considerable water had accumulated in the cylinder during the two hours following the close of the night. If this statement is true, then the cause of these accidents is due, no doubt, to the accumulation of water in the engine cylinders ; the gear speed is high, but on other work no trouble has arisen on account of high gear speed, and the fact that for two years no trouble arose tends to indicate that the fracture of gears and pinions was due to some other cause.

The road machinery is well maintained and offers no more resistance to operation of cable than is found in the best-designed cable railways. The gauge of track is 3 ft. and 6 ins. There are seven right-angle curves in the system, and five curves covering 45° of a circle. Two large steel viaducts form a part of the system. In the Denver machinery, as in other plants, there were indications that more power was being developed than was really necessary for the operation of cable and cars. The grooves in the driving drums were found to be

considerably worn, having irregular depths. The writer had a series of tests made, which were placed in the care of his principal assistant, Mr. Towson. After considerable experimenting and careful testing, it was assumed that on this road the power required to operate various special parts of the cable railway was as follows :

One 90°, 55 ft. radius, double-track curve, 20.64 H. P.

One 45°, 55 ft. radius, double-track curve, 10.34 H. P.

Elevating and depression and let-go sheaves, 0.503 H. P.

Each linear foot of cable, straight track, for cable only (not including engine and machinery resistance), .001612 H. P.

Applying these factors in the computation of power required for the cables in question, and comparing the results with the results secured by actual test at a later date, will be interesting.

TABLE No. 8.

DENVER CABLE RAILWAY TESTS.

Cable No.	Name of line.	Length of rope.	Theoretical power.	Actual power.	Power unaccounted for.	Remarks.
		Feet.	H. P.	H. P.	H. P.	
1.....	Larrimer Street.....	23 100	60.352	126.297	65.945	
2.....	Sloan's Lake.....	31 250	77.514	100.54	23.023	
3.....	Seventeenth Street.....	11 850	26.647	27.827	1.18	
4.....	Welton Street.....	36 850	133.001	208.738	75.727	
5.....	Seventeenth Avenue...	25 297	73 187	74.195	1.008	
6.....	North Denver.....	25 271	52.639	53.595	1.056	
7.....	West Denver.....	28 000	.....	.....	.....	Not in operation.
	Totals.....	.....	423.270	591.192	167.942	

The great difference between what is given as the theoretical test (deductions from experiments), and the power actually developed in the tables, is an evidence of either error or defective machinery. It was due largely to the latter. We were aware, as stated, of the fact that several of the driving drums, which were solid rims, had worn considerably, and needed re-turning in order to secure uniform diameters. The road machinery was all thoroughly readjusted, and the driving drums were accurately turned, securing a uniform diameter, and the inaccuracies corrected. On account of the absence of the engineer, cards were not taken immediately after the drums were turned.

Mr. Towson, however, was in Denver when the drums operating Cable No. 4 (Welton Street Cable) were re-turned and adjusted, and

secured cards from the engine immediately afterwards, which showed an actual saving of 80 H. P. over the power required to drive this cable before the drums were turned. It will be observed that this amount is a little in excess of the amount indicated as the power unaccounted for opposite Cable No. 4, the one in question. After all the tests were carefully examined and compared, the result showed that the total power saved by re-turning these drums and adjusting the road machinery aggregated 200 H. P.

The actual test referred to in Table No. 8 was made as follows:

The total power required to drive six cables empty (without cars) was determined, one of the cables was then stopped, and the power for the remaining five in operation determined.

The difference between the power required for the six cables and that required for the five cables is the power required for the cable in question. This method of stopping one cable and indicating all the others, so that at each indication five cables were in operation, was followed throughout the test, thus securing a result that does not include the loss in transmission through the engine, gears, and main shaft. The clutches were not all in good adjustment when these tests were made, and when all the cables were stopped and cards taken for the engine and shaft resistance, the brake action due to the clutches was such as to make the cards of little value. In making the test below, only one clutch was thrown out during each indication, which was watched and adjusted so that no great error could enter the computation.

The Welton Street cable has three right-angle double-track curves and one 45° curve, and had a cable in use that was made up with large outside wires, making it ridged. This character of cable was adopted for the purpose of securing longer life, which was not realized, but which required a little more power than one with smaller wires on the outside surface of cable.

A good example of power required in operating a cable railway may be found on the Missouri Railway's Olive Street line, St. Louis, Mo. It is double track, 4.75 miles in length. There are two right-angle curves and two curves of 300 ft. radius, 84 ft. long; also one 1 000 ft. radius 30 ft. long, and one 300 ft. radius and 80 ft. long, and two 600 ft. radius and 75 ft. long. The curves outside the right angle curves are not very objectionable.

TABLE No. 9.

1892. (March.) DENVER CABLE RAILWAY TESTS.

Cable No.	Name of line.	Speed of cables per hour.	Length of cables.	Horse-power, first test for cables only.	Horse-power, second test for cables only.	Mean power.	Mean horse-power per linear foot of cable, no cars in operation.	Trains of two cars operated during the following test.	Test of power for cable and trains.	Remarks.
1.....	Larrimer St.....	10	23 100 ft.	125.95	126.645	126.297	.005467	15	Total power developed, all cables, including West Denver, and loads (with cars) July 26th, 1892, 1 146 H. P.; July 27th, 1 115 H. P.; July 28th, 1 155 H. P.; July 29th, 1 118 H. P.; July 30th, 1 236 H. P; July 31st, 1 111 H. P.	Cables connected by brackets are on the same route, and the cars are operated on both; that is, the number of trains operated means number on both cables thus connected.
2.....	Sloan's Lake	10	31 250 "	95.045	106.035	100.540	.003217			
3.....	Seventeenth St...	10	11 850 "	30.925	24.730	27.827	.002348	6		
4.....	Welton St.	10	36 850 "	211.835	205 640	208.738	.005664	12		
5.....	Seventeenth Ave..	10	25 297 "	77.860	70.530	74.195	.002932	10		
6.....	North Denver....	10	27 270 "	51.535	55.655	53.595	.002120			
7.....	West Denver.....	10	28 000 "	.....	.....	.....	.....*	8		*Not in operation and not fully completed.
	Totals	.....	183 617 ft.	593.150	589.235	591.192	.003624	51 trains.	1 147 H. P.	

The above cables are operated from a single power station.

There are two cables, one downtown 23 800 ft. long, and one uptown 25 248 ft. long, giving a total length of 49 048 linear feet, weighing 2.6 lbs. per linear foot. Power required to operate cables, 49 048 ft., and engine only, is 136 H. P., or 0.0028 per linear foot of cable.

The late Colonel W. H. Paine, M. Am. Soc. C. E., and the writer, made tests of the Tenth Avenue Cable Railway, New York City, which was constructed by the late D. J. Miller, C. E., and Colonel Paine, who also constructed the East River or Brooklyn Bridge cable in the same city.

The engines are automatic engines, cylinders 28 ins. diameter by 48-in. stroke, 62 revolutions per minute. The engines and machinery are arranged something like the Denver plant. The resistance of engine and main-shaft resistance was equal to 58.95 H. P. The resistance of engine, main shaft and one set of drums, with their shafts and gears, was equal to 71.74 H. P. The resistance of engine, shafting, one set of drums, gears and cable was equal to 140.29 H. P. Power required per linear foot of cable, 8 miles per hour, not including machinery resistance, 0.0015 H. P.

A paper relating to the subject of cable railways would not be complete without a reference to the Chicago City Railway, for the reason that this road was one of the pioneer roads of the country, and has demonstrated that cable railways can meet all the conditions imposed by reason of climatic changes.

The writer is indebted to Mr. Robert J. Hill, Chief Engineer of this railway, for the information presented relating to it.

There are two power stations in this system, one at Fifty-fifth Street and Cottage Grove Avenue, and the other at Twenty-first and State Streets. The former plant consists of two Wheelock automatic engines, 36 ins. in diameter and 72-in. stroke, and one always in reserve in case of emergency.

The engine operates four cables :

		Length.
No. 10.	Cable Fifty-fifth to Thirty-ninth Street and return	22 572 ft.
No. 11.	Cable Fifty-fifth to Seventy-first Street and return	22 472 "
No. 12.	Cable Fifty-fifth Street to Lake Avenue and return	10 868 "
No. 13.	Cable Hyde Park loop	3 786 "
	Total length of cable	59 700 "

Revolutions of engine, 52 per minute.

The line shaft gears have 35 teeth.

The drum shaft gears have 63 teeth.

The drum shaft revolves at the rate of 28.9 rotations per minute.

The driving drums have a diameter of 13 ft. and 4 ins.

The cables are driven at a speed of 13.76 miles per hour. The total power required to operate all the cables and the machinery without cars is 382 H. P., or 0.0064 H. P. per linear foot. The maximum tension on the cables during operating hours, when travel was at the maximum, equaled 10 420 lbs., or a pull of 0.175 lb. per linear foot of cable. In order to determine the actual work performed and the load on the cables when the cars were in operation, a series of cards were taken from the engines.

From an examination of time tables and trip sheets of conductors, the load on cables can be approximated. The following table gives the result of such tests, based on the indicator cards selected.

Mean powers (maximum), less power to operate empty cables	257 H. P.
Mean load on cables	152.7 tons.
Mean net power per ton of load on cables (maximum)	1.68 H. P.
Mean power of maximum cards	339 "
Mean power of all cards, less power to drive empty cables	138.5 "
Mean power per ton of load, less power to drive empty cables	0.91 "
Mean power (maximum cards) per ton of load on cable	3.77 "
Variation in horse-power per ton of load on cables	1.55 "

Similar tests were made at the Twenty-first Street power station. Engines two in number, cylinder 30 ins. in diameter and 60-in. stroke; same type of engine as is used in Fifty-fifth Street station.

		Length.
Cable No. 1.	Power Station to Madison Street and return	20 302 ft.
Cable No. 3.	Power Station to Wabash Avenue and Twenty-second Street and return	23 620 "
Cable No. 5.	Auxiliary for Cable No. 1, Madison Street	4 600 "
Cable No. 6.	Auxiliary for Cable No. 3	4 700 "
	Total length of cables	53 222 lin. ft.

TABLE No. 10.

1890. CHICAGO CITY RAILWAY TESTS—FIFTY-FIFTH STREET POWER STATION.

TIME.	Maximum horse-power.	Minimum horse-power.	Differential horse-power.	Trains.	Cars.	Passengers.	Tons. Load.	Horse-power per ton. Variation.	Horse-power per ton of load (maximum) less horse-power to drive empty cables.	REMARKS.
5.30 A. M.....	319	319	.....	.....	.....	.....	.....	.....	.....	Empty cables.
6.20 "	506	319	187	15	15	600	124	1.51	4.08	
7.45 "	602	372	230	18	23	720	167	1.38	3.60	
7.55 "	620	326	294	18	23	720	167	1.76	3.71	

Average horse-power, 576. (Maximum cards.)

One train is composed of one grip car and one coach; the cars in the table refer to extra cars in train.

These engines make 55 revolutions per minute. Gear on main shaft has 34 teeth ; spur gear line shaft has 47 teeth ; pinion line shaft has 27 teeth ; spur gear on drum shaft, 53 teeth. Line shaft makes 39.8 revolutions per minute. Drum shafts make 20.27 revolutions per minute. Diameter of driving drums, bottom of grooves, 13 ft. 4 ins. Speed of cables, 9.65 miles per hour. Power required to operate empty cables and machinery, 294 H. P. Tension on cables, 11 420 lbs., or a pull of 0.127 lbs. per linear foot of cable. Power required per linear foot of cable to drive them at normal speed, including machinery, 0.0055 H. P. per linear foot of cable.

Tests were made to determine the power developed during the hours of maximum travel during the morning, with the view of making comparisons with the other tests at Fifty-fifth Street station.

Mean power of maximum cards	642.4 H. P.
Mean of maximum powers, less power to drive empty cables	384.4 H. P.
Mean load on cables	813 tons.
Mean of maximum powers per ton of load	.428 H. P.
Mean power of minimum cards	483. "
Mean power per ton of load, less power to drive empty cables	0.330 "
Mean power during tests, less power to drive empty cables	268.74 "
Mean of maximum powers per ton of load on cables	.792 "
Variation of power per ton of load on cable	.196 "

Tests were made to determine the power required to operate the cables at varying speeds.

At Fifty-fifth Street and Cottage Grove Avenue a speed of 9.65 miles per hour was tested, being the same speed as Cables Nos. 1, 2 and 3, at the Twenty-first Street power station. After the cars had been taken off the various lines for the night, it was found that in order to drive the empty cables at 13.76 miles per hour, 300.6 H. P. was developed, while the power required to drive them at 9.65 miles per hour, only 184 H. P. was developed.

The first test at Fifty-fifth Street developed the fact that the pull per foot of cables, including engine and machinery resistance, was .175 lb., and that made at Twenty-first Street station was .215 lb. per linear foot of cable. The last test at Fifty-fifth Street station demon-

TABLE No. 11,

Chicago City Railway Tests.—(Twenty-first Street Power Station.)

Time	Maximum horse-power, one engine.	Minimum horse-power, one engine.	Four engines, maximum horse power.	Four engines, minimum horse-power.	Difference.	Trains.	Cars.	Passengers.	Tons.	Horse-power per ton. Variation.	Horse-power per ton of load. Maximum.	Remarks.
4.50 A. M....	144.35	.....	294	.....	.....	.....	.....	.....	.....	.....	.....	Cables empty.
7.05 A. M....	142.8	99.7	582	406	176	55	87	3 734	735	.139	.792	
7.16 A. M....	156.3	122.0	636.4	497	139.4	60	95	3 725	780	.179	.816	
7.46 A. M....	174	134.	709	546	163	70	120	4 050	924	.176	.767	

Mean horse-power, 642.4 (maximum cards).

A train is composed of one grip car and one coach. Cars in table refer to extra cars attached to trains.

This test was made with four engines in operation, which explains the references to engines in table.

strated that the pull equaled .137 lb. per linear foot of cable, at a speed of 13.76 miles per hour, and .119 lb. at a speed of 9.65 miles per hour.

This difference, Mr. Hill says, may be accounted for as follows :

"The first test was made when starting the cables in the morning, before any of the bearings were thoroughly warmed and lubricated. The last tests were made at night, after operating hours, and immediately after the cars had been taken off the street. Thus the midnight test offered the most favorable conditions."

The difference in the tests is .038 lb. per linear foot of cable, which Mr. Hill thinks is not excessive when all the conditions are considered. The greatest resistance per linear foot of cable was found at the Twenty-first Street station, in starting in the morning, which amounted to .215 lb. per foot, due, no doubt, to the down-town loops and the circuitous route of the Wabash Avenue cable. The difference between the resistance per linear foot of cable between the Fifty-fifth Street station and the Twenty-first Street station was found to be .04 per cent. The most satisfactory tests were made at the Fifty-fifth Street power station. Here the same cable was operated at varying speeds, and the tests made when the conditions remained unchanged. The ratio of the speeds were 9.65 to 13.76 miles per hour, equal to 1.43; the ratio of the pull per lineal foot is .119 lb., equal to 1.14.

In a letter relating to these tests Mr. Hill says :

"If the pull on the cable was constant, then the horse-power required to pull the cable would be in direct proportion to the speed of the cable, hence 9.65 : 13.76 : : 184 : 262 H. P.; but it was found that it required 300.5 H. P. to propel the cable at a speed of 13.76 miles per hour, and the difference $38.5 \div 262 = 14.7\%$ more power than that which might result from an increase in speed, which must be due to increased friction, etc.

"The cable being increased 43% in speed, calls for a corresponding increase of 63% in horse-power to drive it, from which it can be seen that for each increase of 1% in speed, there should be an increase of 1.47% in horse-power."

The question of engine and machine resistance in transmitting power is a subject that does not receive the attention it demands. Engineers too often underestimate the power lost in its initial transmission, due to engine and machinery resistance. Mr. Alfred Saxon, in a paper read before the Association of Engineers, Manchester, Eng.,

related the results he secured, after making careful tests and experiments of engine and machine friction in numerous cotton mills. He found that the friction under load was greater than ordinarily estimated. Interesting comparisons were made, among which were the following: ten tests of spur-gearing machines developed the fact that the friction under load averaged 25.964% of the indicated horse-power. Eight examples of rope transmission or rope-driving engines showed that under load the average friction was 29.6% of the indicated horse-power.

Belt-driving engines under load developed a resistance of 27.6% of the indicated horse-power. Direct coupled engines showed a resistance of 23.835% of the indicated horse-power.

Mr. Saxon, during his lecture, said: "Spur-gearing engines give best results when not complicated with rope drive. Rope driving engines show the best results at high rope speeds, and that direct driving from main drum is very desirable. Belt-driving engines for developing large powers are only equal to the average rope-driving engine, with fewer advantages in other respects; and finally that the direct acting type of engines is likely to be very efficient."

Comparisons are valuable in considering the question of power transmission as applied to cable railways, for the reason that many engineers favor rope driving, and can see no special advantage in gear transmission, while others favor machinery driven by belt.

In the Kansas City tests, it was found that the average friction of engine shaft and main shafting gears, and not including driving drums, gears and pinions, based on something over 300 indicator cards, averaged 17.11% of the total horse-power developed.

The Cleveland City Cable Railway engines and machinery developed a resistance or friction of 25% of power developed.

Rope and belt driven machinery has the advantage over gearing in that noise is very materially reduced.

We find that the power required per linear foot of cable 1¼ in. in diameter, weighing from 2.5 to 2.6 lbs. per linear foot, operated at the speed given, is as follows:

TABLE No. 12.

Kansas City Cable Railway.

Location.	Length of cable tested.	Speed of cables Miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet			
Troost Avenue.....	33 600	9.7	.0031	Cast carrying pulleys, 12 ins. diameter, $\frac{7}{8}$-in. journal.
Washington Street.....	23 759	8.0	.0029	Cast carrying pulley, 16 in. diameter, $\frac{11}{16}$-in. journal, weight 19 lbs., 32 ft. apart.
Main Line.....	22 000	7.3	.0017	Corrugated steel pulley, 22 ins. diameter, weight 37 lbs., 32 ft. apart.
Main Line.....	22 000	7.3	.0029	Cast-iron pulley, 22 ins. diameter, weight 76 lbs., $\frac{7}{8}$-in. journal.
Independence Avenue..	8 571	8.0	.00296	Cast-iron pulley, 22 ins. diameter, weight 76 lbs., $\frac{7}{8}$-in. journal.
East Ninth Street.....	6 202	8.0	.00508	Curve was probably in bad adjustment.

(Not including engine friction.)

TABLE No. 13.

Cleveland City Cable Railway.

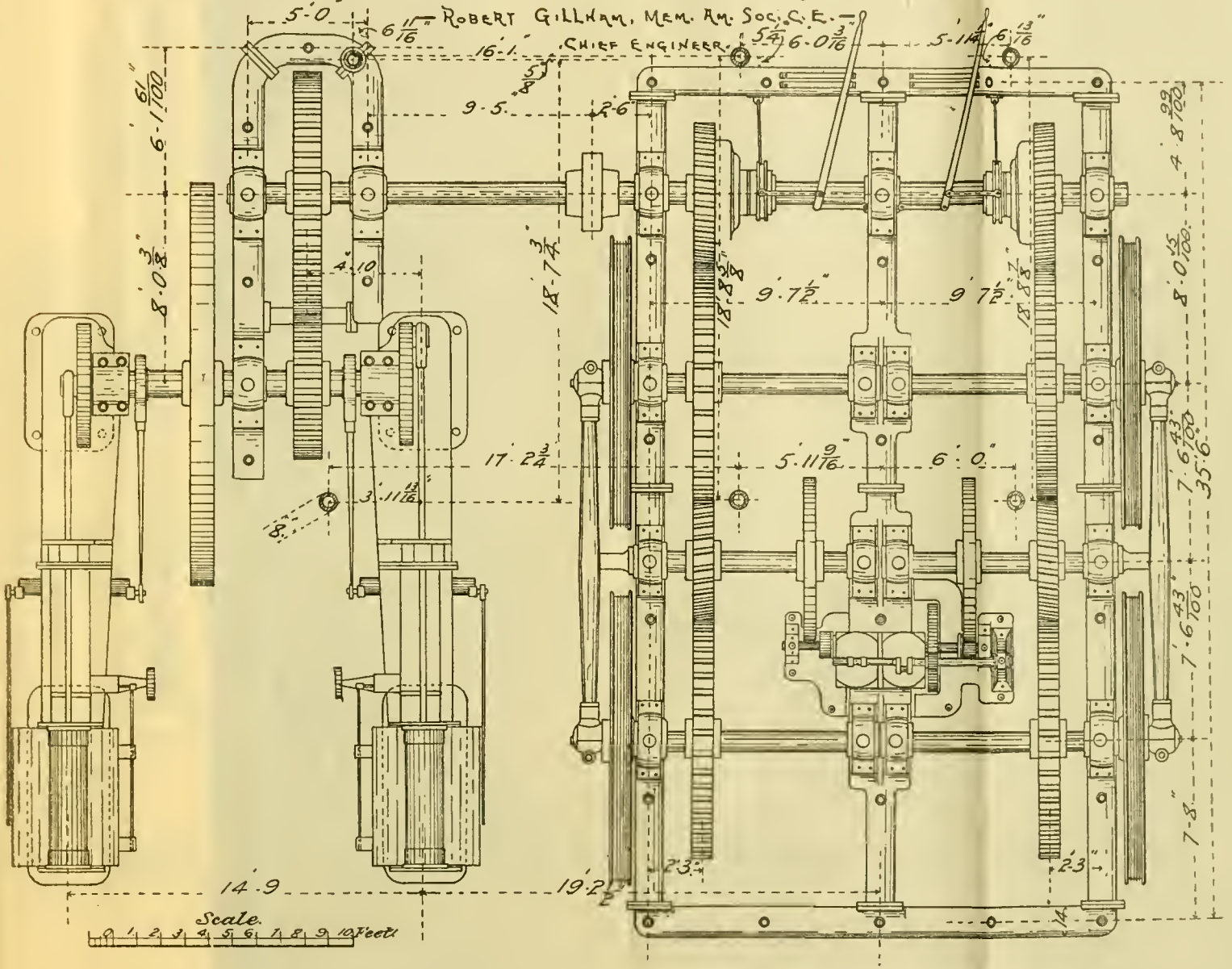
Location.	Length of cables tested.	Speed of cables. Miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet.			
East Superior Street....	23 900	14	0.00328	Practically no curves on this cable.
West Superior Street...	24 300	12	0.00252	Practically no curves on this cable.
East Payne Avenue.....	25 300	12	0.00569	Four right-angle double-track curves.
West Payne Avenue....	24 050	12	0.00233	No curves in this cable.
Water Street Auxiliary..	7 850	4	0.00184	One double-track right-angle curve

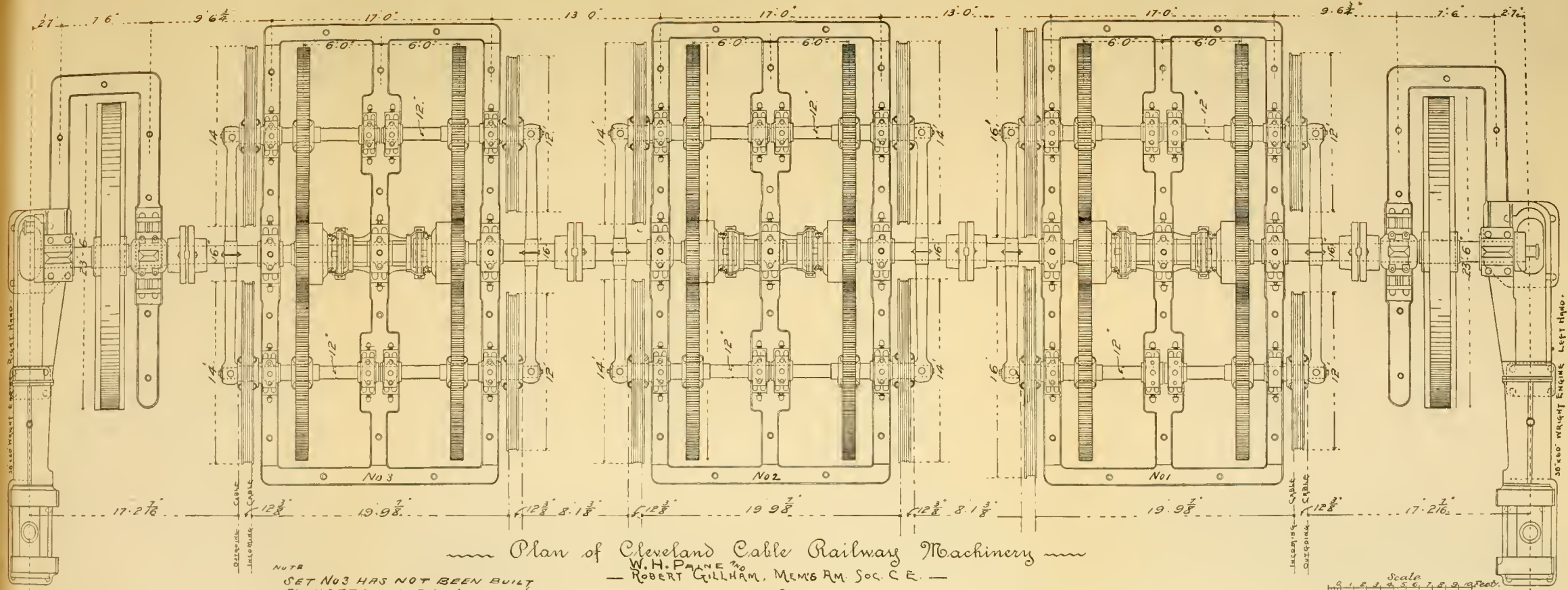
(Not including engine friction.)

VOL. XXIX, No. 623.
TRANS. AM. SOC. CIV. ENGRS.
GILLHAM ON CABLE RAILWAYS.
PLATE I.

Plan of Kansas City Cable Railway Machinery

ROBERT GILLHAM, MEM. AM. SOC. C.E.
CHIEF ENGINEER.





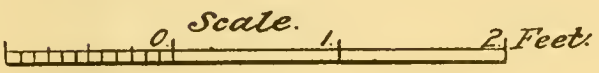
Plan of Cleveland Cable Railways Machinery

W. H. Paine 2nd
Robert Gillham, Mem'bs Am. Soc. C.E.
Engineers

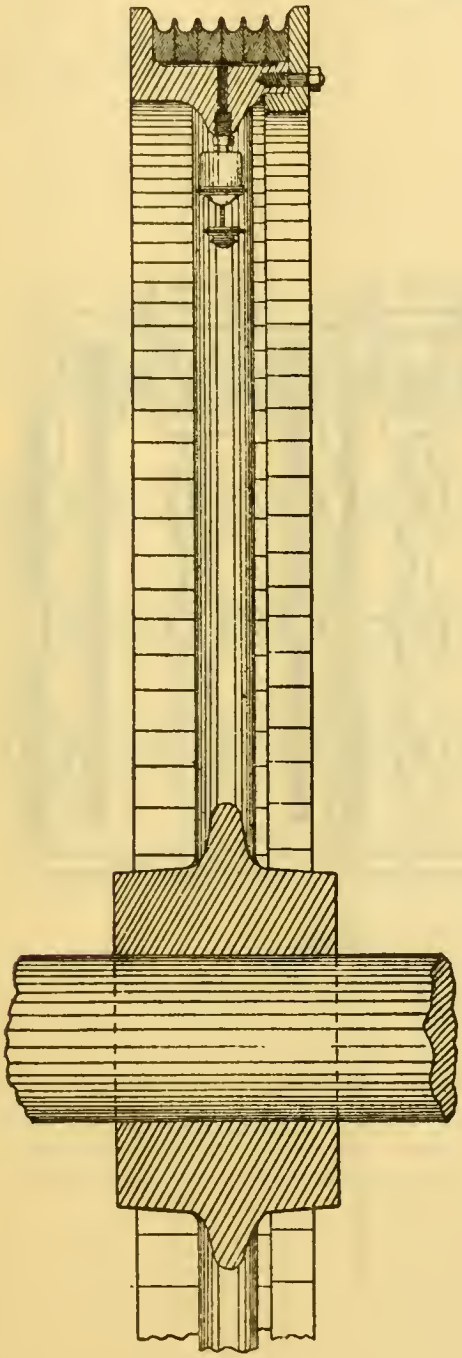
NOTE
SET No 3 HAS NOT BEEN BUILT
FOUNDATIONS ARE IN IN OTHER
RESPECTS DRAWING ILLUSTRATES ACTUAL ARRANGEMENT

VOL. XXIX, No. 623.
TRANS. AM. SOC. CIV. ENGRS.
GILLHAM ON CABLE RAILWAYS.
PLATE III.

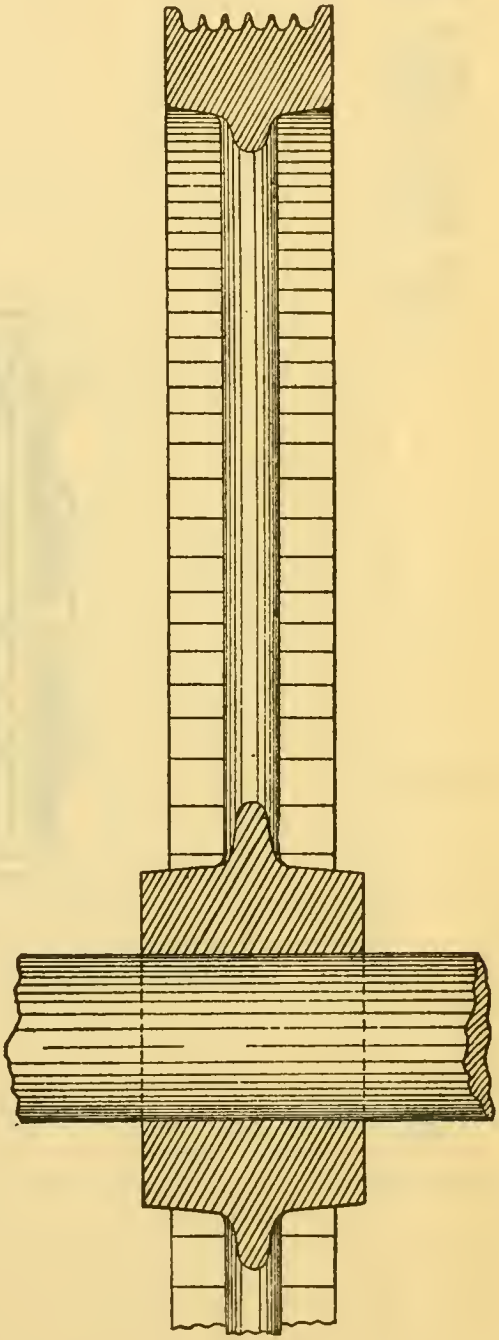
SECTIONS OF WALKER DIFFERENTIAL AND SOLID DRIVING DRUMS.



WALKER.



SOLID.



VOL. XXIX, No. 623.
TRANS. AM. SOC. CIV. ENGRS.
GILLHAM ON CABLE RAILWAYS.
PLATE IV.

Plan of Denver City Cable Railway Machinery

— ROBERT GILLHAM, MEM. AM. SOC. C.E. —
Chief Engineer.

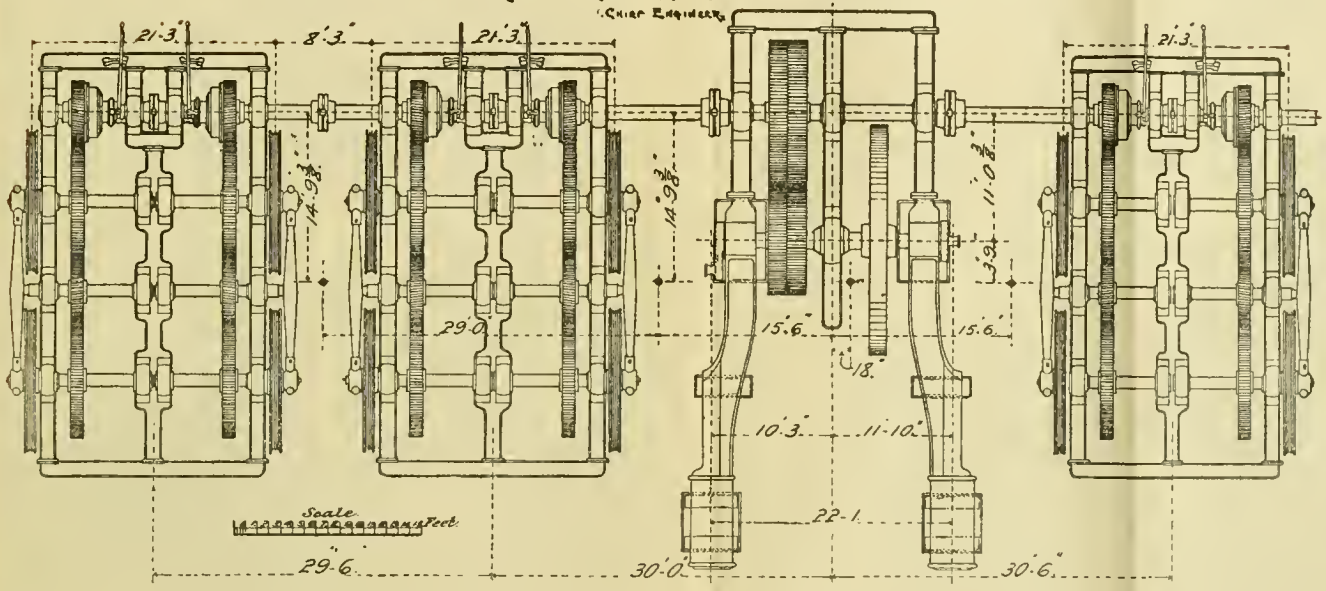


TABLE No. 14.

Denver City Cable Railway.

Location.	Length of cables tested.	Speed in miles per hour.	Horse-power per linear foot of cable.	Remarks.
	Feet.			
Larrimer Street.....	23 100	10	.00546	Conduit was not clean; much dirt in it.
Sloan's Lake.....	31 250	10	.00322	Three double-track cable crossings.
Seventeenth Street....	11 850	10	.00235	Two double-track cable crossings.
Welton Street.....	36 850	10	.00566	Three double-track curves; one double-track cable crossing.
Seventeenth Avenue...	25 297	10	.002932	One right-angle curve and one 60° curve.
North Denver.....	27 270	10	.002120	One 40° curve; one double-track cable crossing.

(Not including engine friction.)

TABLE No. 15.

Chicago City Railway.—(Fifty-fifth Street Station).

Location.	Length of cables tested.	Speed in miles per hour.	Horse-power per linear foot of cable.	Remarks
	Feet.			
No. 10.....	22 572	13.76		
No. 11.....	22 472	13.76	All cables considered .0064.	Individual cables not tested.
No. 12.....	10 868	13.76		
No. 13.....	3 786			

Twenty-first Street Station.

No. 1.....	20 302	9.65	....	Individual cables not tested.
No. 3.....	23 620	9.65	All cables considered .0055.	
No. 5.....	4 600	....	....	Auxiliary cables.
No. 6.....	4 700	....	....	Auxiliary cable.

The tests in this paper are submitted as the result of actual investigations relating to the transmission of power for cable railway operation.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

624.

(Vol. XXIX.—September, 1893.)

THE CONTINUOUS SUPERSTRUCTURE OF THE MEMPHIS BRIDGE.

By GEORGE S. MORISON, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

General Features.—The Act of Congress authorizing the construction of the Memphis bridge specified that the main channel span should in no event be less than 700 ft. in length, nor the other spans less than 600 ft. each in length.

The board of engineer officers from the Engineer Bureau detailed to examine by actual inspection the locality where the bridge was to be built, determined that the channel span should be next to the Tennessee shore, but did not agree as to the proper length of this span. The Secretary of War decided that if the east pier of the bridge was placed at the low water-mark, the channel span might be 700 ft. in the clear, but

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

proper guards would be required to guide tows in passing through the bridge ; at the same time he suggested that if this pier were placed 70 ft. back from the low-water shore line, which would bring the pier in about 9 ft. of water at the highest stage, these guards might be dispensed with.

The latter suggestion was accepted, and the plans which were submitted to and approved by the Secretary of War provided for a channel span 770 ft. long in the clear and two spans of 600 ft. each in the clear, these three spans crossing the entire navigable river. Adding to each span the estimated thickness of the piers at low water, the design called for one span of 790 ft. and two of 620 ft. each measured between centers of piers.

The arrangement which would have been most satisfactory to the Engineer would have been three equal spans of about 675 ft. each. If, however, one span of extra length was required, it would have been preferable to place it at the center, making this central span a cantilever structure, the cantilevers projecting from the ends of two heavy side spans. The arrangement required by the War Department, however, placed the long span next to the east shore, so that if this span was built as a cantilever span it was necessary to provide an independent anchorage on the Memphis bluff. This course was adopted.

The length fixed for the channel span was 790 ft., or 170 ft. more than either of the other spans. By projecting a cantilever 170 ft. long from Pier I (on the Tennessee shore), the distance between the end of this cantilever and Pier IV (on the Arkansas shore) was divided by the two other piers into three equal spaces of 620 ft. each. By making the central span a fixed span with continuous chords, and projecting a cantilever 170 ft. long from each end of this fixed span, there remained two spaces each 450 ft. long to complete the bridge, one of these being between two cantilevers, and the other between a cantilever and Pier IV. With this arrangement the bridge would consist of a central span 620 ft. long, of three 170-ft. cantilevers precisely alike, of two 450-ft. spans also alike, besides the anchorage span east of Pier I.

In order to simplify construction it was desirable to make the panels of uniform length throughout, and this required that the panel lengths should be common divisors of the lengths of the cantilevers, of the suspended spans and of the central span. No such common divisors existed for 170 ft. and 450 ft., but by shortening the length of

the cantilevers to 169 ft. 4½ ins. and increasing the length of the suspended span to 451 ft. 8 ins., 56 ft. 5½ ins. became a common divisor. The lengths were, therefore, slightly changed, and a panel 56 ft. 5½ ins. long was made the unit for the entire bridge, this panel being divided into two panels in the floor system. Each cantilever arm was divided into three panels, each suspended span into eight panels, and the central span into 11 panels.

As the bluff rose rapidly back of Pier I, a long anchorage span was not required, and it was thought best to limit it to such length that there would be no reversal of strains ; it was made four panels or 225 ft. 10 ins. long.

The anchorage span consists of four panels; the channel span of 14 panels, three in each cantilever and eight in the suspended span; the central span of 11 panels; and the west span of 11 panels, of which three are in the cantilever and eight in the suspended span; the total number of panels is therefore 40, and the total length of the continuous superstructure is as follows:

Anchorage arm	225	ft. 10	ins.
Channel span	790	" 5	"
Central span	621	" 0½	in.
West span	621	" 0½	"
Total	2 258	" 4	ins.

The arrangement of these spans is given on Plate I.

As each truss panel is divided into two floor panels, there are 80 panels in the floor system. Moreover, the floor system is extended eastward on a viaduct of three floor panels beyond the anchorage pier, and a deck span of 12 floor panels reaches from the shore side of Pier IV to a special pier (V) built back of the shore line. The entire floor system of the bridge, therefore, consists of 95 panels, and is 2 681 ft. 9¼ ins. long.

The lengths of the spans being fixed, the next thing to determine was the width. The principal limit in determining this was the length of the central span. In the matter of transverse stiffness the position of this span corresponded with the separate spans of a common bridge; whereas, the longer span by its cantilever construction was held rigidly at the ends. The central span being 620 ft. long, it did not seem wise to make the width between trusses less than 30 ft. This

corresponded with widths which have been adopted with good results in shorter spans. The channel spans of the Cairo Bridge are 518.5 ft. long and the trusses placed 25 ft. between centers, the ratio between length and width being almost exactly the same as between 621 ft. and 30 ft. A width of 30 ft. was adopted.

The next feature to determine was the depth of the trusses, and in determining this other considerations than economy of metal-work governed.

The difficulties of erection made it important to keep the dimensions within limits to which ordinary false-work could be adapted. The magnitude of the structure and its cantilever design made it important to use such proportions that vibrations would be reduced to a minimum. It was not thought best to make the depth at any part of the superstructure much more than two and one-half times the breadth of base. The breadth of base could not be increased without increasing the length of the piers, which would have added to the already excessive cost of the foundations. By fixing the depth of both the central and the suspended spans at one-eighth of the span and making all three of the cantilevers alike, the depth of the structure over each of the piers and for the whole length of the central span became 77 ft. $7\frac{13}{16}$ ins., and the depth of the suspended spans, 56 ft. $5\frac{1}{4}$ ins. These dimensions were adopted.

It was at one time proposed to make the central span in eight panels of greater length than those used elsewhere, but as the plans matured this seemed unwise, and a uniform panel length was adopted throughout.

The form of trusses adopted was the double triangular or double Warren girder. It was intended to erect the channel span without falsework, building out from either end, and this form of truss was thought to have advantages in the manner in which it sustained the upper chord from which the work would be done.

The floor system is suspended from the intersection points of the two systems of web members, and the upper chord is supported from the same points by struts.

As the depth of the cantilevers over the piers corresponds to the depth of the central span, while their outer ends correspond to the depths of the suspended spans, the chords are not parallel. The same may be said of the anchorage arm. In order to keep the floor panels

uniform, it was necessary to keep the points of intersection of the web members over the panel centers. This made the panel lengths of the upper chord irregular, but as these chords were formed of eye-bars the irregularity was not material.

The cantilever construction made it possible to bring the weight of the spans on each side of each pier together in a single point and transfer this weight directly to the center of the pier, instead of taking it nearer the edge of the pier as is always done with separate spans. This allowed the use of somewhat lighter piers than would otherwise have been needed, and the increased cost of the superstructure design over three equal separate spans was in a measure balanced by the decreased cost of the substructure.

The only span which is continuous from pier to pier is the central span, and provision had to be made at one end of this span for expansion and contraction. All other expansion was taken up by sliding joints at the ends of the cantilevers. As there are two sliding joints in the channel span and only one in the west span, there was a double chance to take up expansion in the chords and floor system of the channel span. For this reason the west end of the central span was fixed and the east end placed on expansion rollers.

Principal Details.—The general dimensions and form of truss having been adopted, it next became necessary to fix the character of the principal details. The American form of construction with pin connections was adopted from the first. The chords of the central span, being subject to reversals of strains from the action of the cantilevers, were necessarily both made stiff, and the same stiff bottom chords were necessarily extended out as the bottom chords of the cantilevers. The top chords of the cantilevers, being always in tension, were made of eyebars. As the east suspended span (in the channel span) was to be erected without falsework, the two halves being built out as continuations of the cantilevers, it was necessary that the bottom chord of this truss should also be made stiff for the greater part of its length, while the top chord, being in compression in the finished structure, was of course stiff. It was determined to sacrifice some material and to make the bottom chord of the suspended span stiff throughout, and to make both suspended spans (or intermediate spans as they were called on the drawings) with stiff chords throughout. The chords of the anchorage arm correspond to those of the cantilevers. The bottom

chord is therefore stiff throughout the entire length of the superstructure, and the only portions of the top chord which are made of eye-bars are in the anchorage and cantilever arms and in the end half panels of the central span, this special arrangement being adopted from the difficulties of packing a stiff chord into an eye-bar chord at the extreme ends of the span.

The stiff-chord provision undoubtedly adds to the lateral stiffness of the bridge and, to a certain extent, to its vertical stiffness. The sliding joints at the ends of the cantilevers are carefully fitted, and in spite of its cantilever construction the bridge is very free from vibration.

The lateral bracing is formed of diagonal rods attached to pin plates riveted to the chords, and so placed that the axial lines intersect at the center of each chord. The lateral bracing is adjustable, and is the only adjustable portion of the bridge. It would have been preferable to make it stiff, but the plan was adopted in conformity to the practice hitherto followed by the Chief Engineer of the bridge, he not being satisfied with the detail connections of any stiff system which he had worked out at the time these plans were prepared.

The transverse bracing is rigid throughout, and is made in the form of lattice frames, so as to stiffen, not merely the center of each post, but intermediate points above. The principle which led the engineer to adopt this form of bracing was his belief that the two trusses of a bridge should be made as nearly as possible a single truss. So far as the chords are concerned this cannot be done; but if the compression members of the web are united by stiff frames, they become in a large degree a single compression member of the full width of the truss, this single compression member transferring its strain to two chords at the top and two chords at the bottom. This principle of transverse bracing was followed throughout the whole superstructure. In the end posts of the intermediate and central spans and the posts of the cantilevers which carry the weight of the intermediate spans, the stiffening was carried further by extending portal plates down the sides of each separate post, thereby increasing the width of the posts and uniting the two sides with a stiff portal. In the case of the large vertical post over the piers, these portal frames were united with the floor beams below, so that the two posts form from top to bottom practically a single member.

The floor system consists of two stringers placed 8 ft. between centers, these stringers being riveted to the webs of the floor beams at each panel and half-panel point. At the full-panel points the floor beams are supported on short posts to which they are riveted, which posts rest directly on the pins. At the half-panel points the floor beams are suspended from the web intersections above.

Although the width between trusses is sufficient for a double-track bridge, the bridge, being designed but for a single track, has but two lines of stringers. The management did not feel justified, at the time the bridge was built, in bearing the additional expense which a double-track structure would have entailed. It should, however, be mentioned that the Memphis bridge, though designed for a single track only, is at least two and one-half times as strong as some important single-track bridges built less than 15 years ago.

The charter from the General Government required that the bridge should be adapted to the passage of vehicles and animals. This provision is met by making a tight floor 20 ft. wide; on each side of the floor are steel fences supported at the panel points, these fences being in fact lattice girders which carry the ends of the ties and so make practically four lines of stringers. The ties are planked longitudinally with 3-in. pine planks sized to 2¾ ins., and diagonally with 2-in. oak plank sized to 1¾ ins., this making 4½ ins. of solid planking. Between the rails the oak plank is laid longitudinally. It is doubtful whether this expensive highway floor will be much used.

In many respects the design of the superstructure may be criticised as not strictly economical. This is admitted, but such criticisms are ill-considered unless they include, not merely the metal in the superstructure, but all the material in the piers and masonry. The substructure of the bridge, which under the present design cost more than the superstructure, would have been rendered much more expensive by those changes which mere economy of superstructure design called for.

In the design attention was everywhere given to stiffness as well as to strain. This is a matter to which too little attention has been given, and which has often been overlooked in competitive designs. It is perfectly possible to design a structure in which no metal under any ordinary supposition will be overstrained, and yet without such overstrain vibrations can exist which would be utterly inadmissible. This

may occur in trusses of extreme depth, and also in structures with cantilever details in which loose fitting is permitted at expansion joints.

It was with a view to avoid vibrations as much as possible that stiff chords were adopted throughout, and that the principle was followed of uniting the compression members of opposite trusses as far as possible into single members. For the same reason, the sliding joints at the ends of the cantilevers were so carefully fitted that lost motion in these places practically does not exist.

While these ideas undoubtedly made the structure more expensive than a competitive design might have been, the engineer believes that the results fully justify his work; but in studying details these facts should be remembered.

*Special Details.**—With these conditions stated, attention is called to a few of the special details of the superstructure.

1. The stiff chords of the central span, including one full panel of the bottom chords of each adjoining cantilever, were made with four webs. This form of construction was adopted for two reasons. First, to reduce the thickness of the metal and so to reduce the lengths of the rivets in the splices. With the present arrangement the maximum length of rivets is $3\frac{5}{8}$ ins. between heads, and the larger part of the rivets are in double shear, the splices being balanced on the two sides of each web, this being the condition under which the rivets are least likely to get loose and least likely to cause trouble if they become loose. The second object was to reduce the bending strains on the pins; the connections with the web members are all made in the narrow spaces between the outside and the interior webs, so that the pins, by which the whole horizontal strains are transferred to the chords, are supported at four points, and the unsupported length is reduced to a minimum. The objection to high theoretical bending strains in pins is not so much the danger to the structure from the failure of the pins as the fact that by the distortion of the pins the strains may be distributed unequally among the several pieces attaching to them. With the arrangement adopted here, this danger is reduced to a minimum.

The four-web chords are confined to 10 full (20 half) panels of the top chord of the central span, to 11 full panels of the bottom chord of the same span, two full panels of each cantilever arm and two full panels

* The *general* plans of the superstructure are given on Plates II, III, IV, V.

of the anchorage arm. Two-web chords were used in the remaining bottom panels of the cantilever and anchorage arms and throughout the whole length of the suspended spans. In the bottom chords of the suspended spans the rivets became objectionably long.

The sections of the stiff chords were generally made in full-panel lengths, 56 ft. 5½ ins. long, the riveted joints being placed midway between the panel points and over the intermediate points; the only exceptions to this rule were in the upper chords of the intermediate spans and the lower chords of the cantilever arms and anchorage span. The details of the riveted joints are given on Plate X.

2. The shortness of the anchorage arm insures the connection being always in tension and never in compression. The details of the anchorage are given on Plate VI. The masonry of the anchorage pier is built on a platform of I beams. Under this platform are placed steel washer-plates with conical sockets through which the anchor rods pass, the weight being transferred to the anchor rods on conical counter-sunk heads. The anchor rods are built solid into the masonry, and run through steel plates on top. The top of the rod is turned down, and screws of two different diameters are cut on it. The nuts on the lower screw, 3½ ins. in diameter, screw up against the plates on top of the masonry, thus taking up any possible slack in advance of strain. The upper smaller screws, 3⅛ ins. in diameter, carry two nuts, besides a check nut on top, and these two nuts hold between them the cross-blocks which carry the pin on which the outside anchor rods attach. Under each truss there are 16 rods in the masonry, these rods connecting with eight blocks which carry the single pin on which four anchor bars connect. These anchor bars are simply flat bars of steel with pin holes at top and bottom. After the adjustment of the structure, folding wedges were placed between the steel plate and the blocks and tightened up so as to prevent any possible horizontal bending strain on the anchor rods. On the center of the pier was placed a tetrapod of steel, the four corners of which were anchored to the masonry and the apex of which fits into a guide at the center of the end floor beam, the connection being such that no weight can be thrown upon it, but a full horizontal stiffening is obtained.

The general arrangement of the anchorage is such as to place all adjustable or movable parts in the open air above the masonry in plain sight, there being no unexposed portions and no iron-work

buried in chambers, the only iron out of sight being the long rods and the I beam platforms, which being buried solid in Portland cement are protected from oxidation, while there is a large excess of material in the rods.

3. The superstructure and moving load throw on each of the two points of support on Piers I, II and III a weight of about 2 000 tons, this weight, however, being thrown directly over the axis of the pier. To distribute this weight properly on the masonry requires an area of about 100 sq. ft. and a sufficient height between the masonry and the chords of the superstructure to distribute it with some degree of uniformity. On Piers I and III the bearings are fixed. They are shown on Plate VII. In each instance the weight is transferred first to a 14-in. pin passing through the center of the chord. The three posts, one vertical and two inclined, rest on this pin, being made with semi-circular pin bearings at the ends, no pin plates passing around the pins, this arrangement being adopted partly for convenience in erection and partly because the weight always carried here is so great that nothing approaching to tension can ever exist. This 14-in. pin rests on a steel casting, cast with ribs placed directly under the bearings of the posts on the pin. The inclined posts are two-web posts, and the vertical posts four-web posts, but they are so packed that the whole weight is transferred to six ribs in the castings. The steel casting rests on two iron castings which are packed with long bolts and locked together with a grooved steel plate between them. These two castings rest again on four castings, which are locked together in the same manner at the center. The whole was fastened together by turned bolts passing through drilled holes. The actual weight of each pedestal casting between the pin and the masonry is about 45 tons. The center of the 14-in. pin is 9 ft. 10 ins. above the masonry, which brings the top of the stringer of the bridge 13 ft. above the masonry.

4. On Pier II the bearing, which carries the same weight as those on Piers I and III, had to be made an expansion bearing to allow of the expansion of the central span, temperature alone here representing an expansion of about 8 ins. It is shown on Plate VIII. The piers are slender and the expansion great; it was therefore deemed necessary to provide a joint which would move with the least possible friction and which should not be liable ever to become clogged or stopped by the collection of dirt. The joint must also be so arranged that the struc-

care would be held laterally and the motion limited longitudinally. It was therefore determined to use rollers 15 ins. in diameter and to make these segmental rollers of a pattern resembling the European practice, the rollers being placed 6 ins. between centers.

Each expansion bearing as constructed consists, first, of a steel casting precisely similar to those used at the fixed end. This steel casting rests on a bolster composed of a horizontal top plate, then of eleven 12-in. I beams running transversely, of a second horizontal plate, of sixteen 12-in. I beams running longitudinally, and of a third and thicker horizontal plate, the lower surface of which is polished smooth. It had originally been intended to make this bolster of two steel castings with a planed steel plate between them, and this arrangement would have been preferred; but the delays in getting the castings and the uncertainty of securing the finished product in time, made it necessary (after three castings had been made and rejected) to change the plan.

Under the bolsters came the rollers. The rollers are in two lengths and are separated by two steel guide-plates, one of which is built in between the polished bottom plates of the bolster and the other between the iron castings below. These serve as the transverse guides. There are 30 rollers in each joint, 15 on each side of the central guides. The rolling surfaces of these rollers are polished, and each roller has two holes drilled completely through it, through which pass turned rods, so that the rollers on one side of the center must always work with those on the other, while the distances between the rollers are kept constant by two side-plates drilled to fit the rods, the rods being held in place by nuts outside the side-plates. The upper side-plates are made with hooked ends, which, striking against the ends of the lower side-plates, limit the possible motion of the rollers and prevent any possible overturning.

Under the rollers is the bearing plate (commonly called the rail plate). This is of the pattern which the Engineer has used universally for the last 10 years. It is formed of T rails riveted on a plate below, the tops of the rails being about $\frac{1}{4}$ in. apart and the top surfaces planed and polished. This arrangement makes a stiff surface for the rollers to roll upon and provides adequate means for cleaning. The rail plates are in two parts, divided by the center plate which guides the rollers.

The motion of the top bearing is further limited by a lock plate which is fitted over the lower guide plate, the upper jaws of which would strike the edges of the top bearing plate before a motion could occur which might cause the top plate to slide on the rollers.

Under the rail plates are the castings, which bear directly on the masonry and are like the lower sections of the fixed end castings.

The result of this arrangement is a very sensitive and very powerful expansion bearing. For convenience of observation it was fitted with vernier scales, and the record which has been kept of the motion so far, indicates that this bearing works practically without friction.

5. A somewhat different form of support was used at the end of the intermediate span over Pier IV. This is shown on Plate IX. Here, also, the weight is distributed on the masonry by iron castings, and the weight is transferred to the iron castings through a pin on a steel casting ; but the pin is placed below the level of the chord, the whole weight being transferred by a small upright support, which also holds the floor beam. While this works fairly well, it is not as satisfactory a detail as the other bearings. It was adopted with a view to keeping the construction of this particular panel point as nearly uniform as possible in the four places where it occurs, this supported upright taking the place of the suspended uprights at the other three points.

6. The expansion between the cantilevers and the suspended spans is taken up by sliding joints in the top and bottom chords, the long suspender swinging. No special addition was made to this suspender in consequence of this swinging motion, the extra strain which can possibly be produced in this way being less than that which is usually produced in horizontal eye-bars by their own weight. The sliding joint in the bottom chord is placed in the last panel of the cantilever. The sliding joint in the top chord is placed in the first panel of the suspended span. As the end web members of cantilever and suspended spans are parallel compression members, both of these sliding joints come where no strain exists.

The sliding joint in the bottom chord is shown on Plate XII. It slides between polished steel surfaces with a play of only $\frac{1}{32}$ in. This joint is placed near a floor beam, and the lateral system of the cantilever arm ends at this floor beam, which forms the lateral strut. The lateral system of the suspended span ends on the other side of the sliding joint, there being an independent strut to hold the two chords in

position; this strut was put in after the erection of the superstructure, the pin holes being reamed in position. There is no observable lost motion at this joint. The top lateral strains are transferred at the ends of the suspended spans to the bottom chord by the portal bracing, and there is no lateral system in the top chord of the end panels of the suspended spans. The sliding joint in the top chord is made, therefore, simply an oblong pin hole between two sets of stiffened tension members. The same oblong pin hole was used in the bottom chord joint, but principally for necessities of erection.

7. The large expansion existing at the ends of the suspended spans made some special expansion arrangement necessary in the connection between the stringers and the floor beams. An ingenious arrangement to accomplish this end was designed by Mr. Ralph Modjeski, Assistant Engineer, and is shown on Plate XII. It dispenses entirely with a long sliding surface and supports the end of the stringer perfectly.

8. As the end of the anchorage arm consists only of tension members, it was difficult to make a satisfactory form of portal which would at once resist vibrations and have the substantial appearance which seemed important in the most conspicuous part of the bridge. The result was accomplished by making a stiff frame, entirely independent of the tension members, consisting of posts placed between the inclined eye-bars of the end panels, these posts being connected by a stiff strut at the center, and the rectangular panel above divided by stiff diagonals. This stiff frame is attached to the pins of the truss, but the pin holes in the stiff posts are made 1 in. larger than the diameters of the pins, so that the tensile strains should not be disturbed.

Loads.—The views of the Chief Engineer have long been opposed to proportioning bridge superstructures for precise wheel-base loads, these precise loads being always those of a special locomotive, either actual or assumed, and subject to constant change. The superstructure of the Memphis bridge is proportioned in accordance with the practice now followed by that Engineer, the load per foot on a length of 20 ft. being taken as twice the load per foot on a length of 120 ft. and upwards, and the load per foot being increased by 1% for each foot in length less than 120 ft. The excess variation in web members, being the difference between the strains produced by a moving load and by a fixed load of equal intensity, is taken on a basis one-half greater than the uniform moving load. In the case of the Memphis

bridge the unit load was taken at 4 000 lbs. per foot of track, and the wheel-base load on 20 ft. was consequently 8 000 lbs. per foot of track, while the stringer load, the panels being a little more than 28 ft., was taken ($4\,000 \times [1 + 0.92] = 7\,680$) at 7 680 lbs. per foot of track. These weights were used in calculating the live loads given on the strain sheets shown on Plates XIII to XVII inclusive.

In the central span the dead load was assumed in the strain sheet at 4 000 lbs. per linear foot of truss, or 8 000 lbs. per linear foot of bridge, being just double the assumed live load. In point of fact, the actual weight of this span is 8 300 lbs. per linear foot, exclusive of end posts, which stand directly over the piers. This excess of weight amounts to less than 4%, and is no greater than the difference in weight between the kind of floor used on this bridge to accommodate highway traffic and the usual railroad floor.

In the intermediate or suspended span the dead load was assumed at 5 400 lbs. per linear foot. In point of fact it is 5 660 lbs., or a little less than 5% in excess of the calculated weight, the actual difference being almost exactly the same as in the central span.

In the anchorage and cantilever arms no fixed rate of dead load was assumed, but the strain sheet was made by assuming the estimated weights of the different members as concentrated at the separate panel points, these concentrations, of course, being greatest nearest the piers. In every case the weight of a tension member was supposed to be carried at the upper end of that member, and the weight of a compression member to be carried at the lower end of that member, this, of course, only applying to the resultant portion of that weight which moved in the direction of the axis of the member. The panel point loads are given on the strain sheets.

The upper lateral system is proportioned to resist a horizontal pressure of 300 lbs. per linear foot of bridge. The bottom lateral system is proportioned to resist a horizontal pressure of 600 lbs. per linear foot. In both instances the whole horizontal pressure is treated as a moving load. This differs from the usual practice; but the allowance made for moving loads is inadequate rather than too great, as it is among the possibilities that when half of a span is exposed to a wind pressure in one direction, the other half may be exposed to a wind pressure in precisely the opposite direction.

No allowance is made in the strain sheets for the disturbances of

the distribution of weight by wind pressure. A simple calculation showed this to be unnecessary. The lateral pressure on the top chord will exercise its greatest disturbing effects in the central span. Taking this pressure at 300 lbs. per foot, multiplying it by the depth of the truss, and dividing it by the distance between truss centers, we have a resultant of 800 lbs. as the possible increase of weight on one truss due to this cause, this being 20% of the estimated dead load and 13% of the estimated total load. If we take a wind pressure of 400 lbs. per linear foot applied on a train of maximum weight at an average elevation of 8 ft. above the rails, the effect of this wind pressure is to move the center of gravity of the moving load 0.75 ft. from the center of the track ; as the center of the track is 15 ft. from the center of each truss, this increases the moving load carried by one truss 5% and diminishes that carried by the other 5%, thus actually increasing the weight thrown on one truss 100 lbs. Taking these two disturbances together, the total extreme weight which can be thrown on one truss amounts to 900 lbs. per linear foot or 15% above the assumed calculations.

No addition was made to the chord sections to provide for lateral strains. The assumed lateral force on the bottom chord is 600 lbs. per linear foot ; the assumed total weight carried by each truss is 6 000 lbs. per linear foot ; the depth of the trusses is 2.6 times the distance between centers of trusses, so that the strain thrown into the chords by the lateral system is equal to 26% of that thrown in by weight. In the top chord the effects of the lateral strain would be one-half this amount, or 13 per cent.

As the effect of the disturbance in weight by wind pressure is to increase the tension in the leeward bottom chord 15%, while the effects of the strain in the lateral system are to increase the tension in this chord by 26%, the total effect is an increase of tension of 41% in the leeward chord and a corresponding reduction of tension on the windward chord. In the top chord the effects are much less. With the unit strain allowed these strains are well within safe practice.

Proportioning of Materials.—The entire superstructure of the Memphis bridge is of steel, and it was all worked as steel, the rivet holes being drilled in all principal members and punched and reamed in the lighter members.

The tension members were proportioned on the basis of allowing

the dead load to produce a strain of 20 000 lbs. per square inch, and the live load a strain of 10 000 lbs. per square inch. In the case of the central span, where the dead load was twice the live load, this corresponded to 15 000 lbs. total strain per square inch, this being the greatest tensile strain.

The compression members were proportioned on a somewhat arbitrary basis. They were generally designed so as to make them of symmetrical section, and almost always so as to make them symmetrical about the line dividing the least transverse dimension. No distinction was made between live and dead loads in proportioning compression members. A maximum strain of 14 000 lbs. per square inch was allowed on the chords and other large compression members where the length did not exceed 16 times the least transverse dimension, this strain being reduced 750 lbs. for each additional unit of length. In long compression members the maximum length was limited to 30 times the least transverse dimension, and the strains limited to 6 000 lbs. per square inch, this amount being increased by 200 lbs. for each unit by which the length is decreased.

The form of the structure is such that reversals of strains occur in the web members of both central and intermediate spans and in the chords of the central span. Wherever this occurs the member was proportioned to resist the sum of compression and tension on whichever basis (tension or compression) there would be the greatest strain per square inch; and, in addition, the net section was proportioned to resist the maximum tension, and the gross section to resist the maximum compression.

The floor beams and girders of the floor system were calculated on the basis of the moment of inertia, the strain being limited to 10 000 lbs. per square inch in extreme fibers. In the floor beams the rivet holes in cover plates and flanges were deducted. In the stringers, where there are no cover plates and pains were taken to avoid rivet holes in the flanges, the gross section was used.

The rivets, all of which are of steel and in drilled or reamed holes, were proportioned on the basis of a bearing strain of 15 000 lbs. per square inch, and a shearing strain of 7 500 lbs. per square inch, and special pains were taken to get the double shear in as many rivets as possible. This was the requirement for shop rivets. In the case of field rivets, the number was increased one-half. In the splices of the

chords of the central span, which is strained both in tension and compression, but in which the faced ends of the several sections were carefully fitted to close bearings, the number of rivets was based on the sum of the two strains; but the increase in the number of field rivets over what would have been required for shop rivets was made 25 instead of 50 per cent. The chords of this span are of uniform section throughout, and all the riveted joints are alike.

The pins were proportioned on the basis of a bearing strain of 18 000 lbs. per square inch and a bending strain of 20 000 lbs. per square inch in extreme fiber, the diameters of the pins being never made more than one inch less than the width of the largest eye-bar attaching to them. Special pains were taken in packing the pins to divide the strains from the members on one side among those of the members on the other side, the general principle being to take the strain in each eye-bar by itself, and consider that one-half of it goes into the eye-bar on either side leading in the other direction. With this system of packing, the bending strain in extreme fiber is a matter of little importance.

The weight on the rollers of the expansion joint on Pier II is 40 000 lbs. per linear foot of roller, or 3 333 lbs. per linear inch, the rollers being 15 ins. in diameter.

Material.—As the sections of the superstructure were necessarily unusually heavy, and the strains from dead load were greatly in excess of those from moving load, it was thought best to use a slightly higher steel than is now generally used for lighter structures, and to work this steel without punching, all holes being drilled. A somewhat softer steel was used in the floor-system, lateral connections and other lighter parts.

The details of the requirements both for steel and manufacture are given in the Specifications dated January 4th, 1890, which accompany this paper, marked Appendix A. The principal requirements which were to be obtained as the results of tests on samples cut from finished material were as follows :

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in....	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.....	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.....	18	22	28
Minimum percentage of Reduction at Fracture..	38	44	50

A piece of each sample bar was also required to be bent 180° and to close up against itself without showing any crack or flaw on the outside of the bent portion.

The specifications as originally drawn provided for a preliminary test on a ¾-inch round bar, and allowed the steel to be made by either the open-hearth or Bessemer process. So much difficulty was experienced, however, in getting a satisfactory Bessemer steel, that the requirements for the preliminary test on the round bar were so much reduced as to amount to little, and all steel was required to be made by the open-hearth process. These requirements appear in the supplemental Specification dated May 6th, 1890, which is attached to this paper and marked Appendix B.

After the first tests had been made on full-sized eye-bars, it appeared expedient to adopt for this purpose a steel midway between the high grade and medium steel of the former specifications, and steel of the following requirements, denominated eye-bar steel, was prescribed thereafter :

	Eye-Bar Steel.
Maximum Ultimate Strength, lbs. per sq. in	75 000
Minimum Ultimate Strength, lbs. per sq. in	66 000
Minimum Elastic Limit, lbs. per sq. in	38 000
Minimum percentage of Elongation in 8 ins	20
Minimum percentage of Reduction at Fracture	40

These requirements were provided for in a supplementary Specification dated January 1st, 1891, which accompanies this paper and is marked Appendix C.

The results showed that this material was thoroughly satisfactory for most of the purposes for which it was wanted. It was specially so in the 10-in. eye-bars which form the tension members of the anchorage and cantilever arms and of the webs of the central span. The smaller eye-bars which suspended the intermediate points did not give quite as satisfactory results. Tests were made of 56 full-sized eye-bars, and the results are given in Appendix D, attached to this paper. An inspection of this list shows the excellent character of the 10-in. bars.

Owing to the difficulty of getting satisfactory small bars, the sizes of the suspenders which support the floor beams at the intermediate points were increased from 6 x 1$\frac{3}{16}$ ins. to 7 x 1$\frac{5}{16}$ ins., and from 6 x 1$\frac{1}{8}$ ins. to 7 x 1$\frac{3}{16}$ ins., and a softer steel was accepted than the specifications required. A corresponding change was made in the diagonal eye-bars of the intermediate span last manufactured, the width of these bars being increased from 8 to 9 ins., with no other change.

The results of these tests and observations on other work seem to indicate that in large bars a comparatively high steel gives the best results, and, if they are well annealed, is quite as soft as it is desirable to have. On the other hand, in small bars as low a steel as is consistent with sound ingots is probably the best material, but it must be remembered that in trying to get a very soft and ductile steel the chance of blow-holes and other unsound features is increased. For one other reason the use of a higher steel for heavy eye-bars seems wise, as where heavy bars are used it may generally (though not always) be assumed that the strain due to live load is small in proportion to that due to dead load.

In the west intermediate span, being the one which was built by A. & P. Roberts & Co., the riveted members were made of medium steel throughout, the work being punched and reamed. In the other intermediate span the requirements of the specifications were adhered to.

Contractors.—The contract for all the material for the superstructure was originally taken by the Union Bridge Company, and about five-eighths of the whole was actually manufactured by them at their shop at Athens, Pa., the remaining three-eighths being made at various other places. The largest contract placed elsewhere was with A. & P. Roberts & Co., who built one of the intermediate spans (as well as the deck span west of Pier 4, except the eye-bars), the Union Bridge Company relinquishing this portion of their contract and a new contract being made with A. & P. Roberts & Co.

The other shops generally did their work as sub-contractors for the Union Bridge Company, though in some cases special things were ordered direct.

The actual weights and percentages manufactured by the different shops were as follows, the deck span west of Pier IV being included in this statement :

	Pounds.	Percent.
Union Bridge Co.....	10 432 020	63.9
A. & P. Roberts & Co.....	3 113 250	19.07
Elmira Bridge Works.....	1 127 584	6.94
Lassig Bridge and Iron Works....	806 617	4.94
Scaife Foundry and Machine Co...	423 963	2.59
Keystone Bridge Co.....	310 585	1.90
Pittsburgh Steel Casting Co.....	61 935	0.37
New Jersey Steel and Iron Co.....	40 712	0.25
Pittsburgh Bridge Co.....	7 171	0.04
	16 323 837	100.00

The work manufactured by the Elmira Bridge Works consisted principally of web members of the central and intermediate spans.

The Lassig Bridge and Iron Works furnished the four vertical posts and portals at the ends of the central span besides some other web members.

The Scaife Foundry and Machine Company furnished the large castings on the piers.

The Keystone Bridge Company furnished the anchor rods within the masonry of the anchorage pier, a quantity of eye-bars and the bearing plates upon the rollers on Pier II. The Pittsburgh Steel Casting Company furnished the steel castings over Piers II, III and IV. The 15-in. expansion rollers, which were very finely finished, were made by the New Jersey Steel and Iron Company.

All the steel used in this bridge (except a small portion of that manufactured by A. & P. Roberts & Co.) was made by Carnegie, Phipps& Co., Limited (now the Carnegie Steel Company). It was all open-hearth steel, and a large portion of it was made in basic furnaces.

The work was manufactured in the several shops named, according to working plans prepared by the engineer of the bridge, and shipped to the bridge site ready for erection.

Erection.—A contract was executed on the 10th day of May, 1890, with William Baird and Andrew Baird, comprising the firm of Baird Brothers, for the erection of the superstructure for a fixed sum, this sum being divided between the several spans. The contractors received the material as it arrived, took responsible care of it and erected it in position. The requirements which governed this erection are contained in the specifications which form Appendix A attached to this paper.

All of the bridge except the suspended span between the cantilevers of the channel span was erected on falsework. This suspended span was projected from the ends of the cantilevers, connected at the center and then swung free.

Bents were placed under the panel points of the trusses. Each bent had nine posts, the center post and the third post from each side being plumb throughout, the other posts battered. All posts were of 12 x 12-in. timber, and the bents were built in three stories. The falsework was braced longitudinally by girths at each story, the girths at

the ends being bolted to the stone piers. Each bent rested on 18 piles, these piles generally being cut off at elevation 205 or 11.2 ft. below high water. On the top were placed 20 lines of stringers, four at the center and eight on each side, to carry the traveler tracks.

This falsework terminated at the proper level to receive the bottom chord. Four lines of rails, two on each side, were laid to carry the traveler, which was made long enough to reach over one and one-half full panels, or three floor panels, being composed of four bents.

The material for the anchorage arm and the adjoining cantilever was received on cars at the top of the bluff east of Pier I. All other superstructure material was received in a yard under the bluffs, where it was stored and subsequently handled by barges.

Erection was begun on the east shore, and the traveler was set up on the ground back of Pier I; on the 31st of March, 1891, this traveler was completed and ready to begin work, the false-work at that time only extending as far as Pier I. The first piece of bottom chord section was placed on the 3d of April, and the anchorage arm was virtually completed on the 6th of May. Meanwhile the false-work had been extended westward to the end of the east cantilever arm, and the erection of this cantilever arm was practically completed on the 20th of June, though the false-work and traveler were maintained in this position and some further work was done on the last panel as late as July 31st.

The driving of the false-work for the central span was begun in July. The work was begun west of Pier III, the piles for six bents being driven west of that pier. The two westward bents were placed close together, and on top of these were erected derricks by which the material was lifted from barges. The entire false-work between Piers II and III was completed by the end of August. This false-work was placed in the middle of the Mississippi River immediately after the flood season. It was very heavy and expensive, the piles generally being from 90 to 100 ft. long and driven about 20 ft. in hard sand below the bottom of the river.

When this false-work was completed the traveler which had been used on the east side was taken down and set up on the false-work. It was in itself a pretty large structure, standing 97 ft. above the track on which it ran and nearly 200 ft. above the surface of the water.

This traveler when completed consisted of four bents, only three of which had been used on the east side.

Two derricks were set up at the west end of the false-work west of Pier III, and all the members of the central span were taken by barges from the material yard under the bluff on the east side of the river to the west end of the false-work, where they were raised by the derricks to the floor level, there placed on push-cars and carried out to the traveler by which they were put in position. Everything was handled by steam, the engines being placed near Pier III.

The erection began with the placing of the first piece of the bottom chord on September 13th, 1891, the castings and the expansion bearing on Pier II having been previously erected. The entire bottom chord was put together and riveted up, the riveting being generally done by air riveters carried on a special small traveler. These riveters were of two patterns, one designed by Mr. Charles Vogel under the direction of the Chief Engineer, and the other, by the Allen Riveting Machine Company, of New York.

On the 25th of September the erection of the web members began. The erection was begun one panel east of the center, and the traveler moved westward. On the 3d of October the end posts at the west end of the span were placed; the traveler was then moved eastward, and on the 11th of October the end posts at the east end were placed. The span was swung on the 15th of October, 1891. The erection from the placing of the first chord section to the swinging of the span occupied 32 days.

This span, the total weight of which is 5 122 252 lbs., is believed to be the heaviest and longest span that was ever erected on false-work. A single member, the section of top chord between panel points U1 U3, weighed 61 944 lbs.

On the completion of the erection of this span the false-work was driven for the cantilever which projects from the east end of it, and this cantilever was also raised with the traveler, it being completed on the 31st of October.

The traveler was then moved to the west end of the span; the false-work was removed from under the east projecting cantilever and the eastern end of the span, to the span between Piers III and IV. On the 24th of November the western cantilever was completed. On the 7th of December the entire false-work was finished so that the erection of

the suspended span reaching to Pier IV could begin. The bottom chord of this span had to be riveted before it was swung, but the connections were all made by December 16th.

This completed the erection of the continuous superstructure except the suspended span over the channel. The traveler which had done its work was now taken down and the false-work removed.

The actual erection of the last suspended span, the only portion of the Memphis bridge which was erected without false-work, was begun on the 9th of February. A traveler of simple character, which consisted of a platform resting on the top chords and carrying two derricks guyed to a stiff frame, was set up at the east end of the west cantilever of this span (this being the cantilever which projects from the east end of the central span). The material was taken out in a barge under these derricks and lifted into position.

The weight of this suspended span was so great that the chief engineer hesitated about employing the adjustable wedges which have been used on similar structures at the connection between the cantilever arm and a suspended span. Oblong holes, each carrying two pins, were placed at the sliding joints (see Plate XVIII), and by placing adjustable wedges between these pins the position of the end of the projecting span could have been raised or lowered, or the span could have been moved backward. The engineer, however, decided to erect the west end without any adjustment and the east end with a hydraulic adjustment, and to make the connection between the bottom chords with eye-bars, which, acting as a toggle joint, could take up variations of length. The engineer now admits that this was an error in judgment. Wedges could have been used to better advantage than the fixed connections at the west end or the hydraulic connection at the east end. The hydraulic connection at the east end was used only in the bottom chord, a double wedge arrangement being used in the top; the double wedge is not as good as the single wedge.

After the cantilever arms had been built out, the opening between them, which had been carefully triangulated, was measured direct with a steel wire. Computations were made showing the changes in length of the members of the central span, the anchorage span and the cantilever arms, resulting from the building out of the half spans of the intermediate span. The positions of the ends of the cantilever arms at the adjustment point under that condition were then calcu-

lated, as well as the form of the half span when built out. These calculations gave data for fixing the distance between the adjustment pins of the first half span (the west one) that was built. The distance between these pins, which determined the position of the free end of the half span when built out, was fixed by stationary castings (shown in Plate XVIII); these were made in two parts for convenience in handling. After the erection of the half span had been commenced, no change could be made in its final position.

When calculating the final position of the half span, it was assumed that the erecting outfit of traveler, engines, lines and scaffolds would remain on it until the span was swung. This was an error; the unusual weight of the span insured much difficulty in swinging, and it should have been assumed in the first place that all appliances not absolutely necessary in swinging the span would be removed as soon as the half spans were built out. They were removed, and the free end of the west half span, after their removal, was 5 ins. above the elevation intended; this added materially to the subsequent difficulties.

The adjustment pins and castings for the west half-span were placed February 9th and 12th. Erection was proceeded with and the half span erected to within one panel of the center of the span during the next 20 days. The traveler used for this purpose was then removed, and the erection engine, lines, etc., run back to the end of the cantilever arm.

The distance fixed between the adjustment pins had been based on calculations of extensions or contractions due to the increased strain resulting from the building out of the half spans; these computed changes in length were applied as corrections to the measured distance across the opening between the cantilever arms. The corrections to the upper chord opening depended on computed changes in length of chord members for a distance of 1 863 ft.; the corrections to the lower chord opening depended upon computed changes in length for a distance of 1 411 ft. A slight error in the assumption as to loading would produce an appreciable difference in the total extension or contraction in these distances; moreover, the members were in the main riveted members with heavy splice plates, tie plates and lattices, all of which increased the average cross-sections, so that with a correct strain sheet the calculated changes in length might be to a considerable extent in-

exact. It was therefore thought necessary to provide for a small adjustment for the east half span.

Wedges (shown in Plate XVIII) were made for the upper chord adjustment. They provided for a total variation in distance between pin centers of only 1 in. Some small variations from plan dimensions reduced this range to about $\frac{7}{8}$ in.

The removal of all appliances from the west half span not only caused the free end to rise above the elevation intended, but, by reducing the strains in all members, caused the free end of the upper chord to be about 1 in. west of the place expected. On the other hand, the time required for erecting the span was greater than had been expected, so that the connection at the center was made later in the season and at a higher temperature than had been assumed. These two changes in condition almost balanced each other.

It was expected that the wedges would be immovable after the half span had been built out its full length; they were to be used, however, for a final adjustment after the half span had been built out half its length. Before beginning the erection of the half span, the distance across the opening was again measured and the wedges placed at nearly mid-position, the measurement having checked previous measurements and computations within a small part of an inch. After the wedges had been placed and the erection of the half span commenced, the adjustment was not changed until the span had been released at the adjustment points at the west end.

When an attempt was made to move these wedges, the double wedge was found defective. One of the wedges would move first; the immediate result was a great increase of pressure on the other wedge applied at its small end; this fixed it in place, and as the screw was turned to continue the withdrawal, the movement of the first wedge continued until some means were used to prevent its movement.

For the lower chord adjustment at the east end of the span a hydraulic jack (Plate XVIII) was provided for each truss. Each jack had a plunger 14 ins. in diameter, with a stroke of $3\frac{1}{4}$ ins. One force-pump was provided for operating these jacks; it was of special design and very simple in construction. The ordinary leather cup-packing proved inadequate and was replaced by soft lead. The adjustment in the lower chord was simply the thrusting out of the hydraulic jacks to the proper distance, to give the end of the half span, when built out, the

same elevation as the end of the west half span, already built. The stroke of the jacks was not enough for this, but this was provided for by placing crescent-shaped fillers in the elongated pin-holes between one of the pins and the webs of the chord. When the half span was built half its length, the jacks were used to increase the distance between the adjustment pins ¼ in. With this adjustment the limit of the capacity of the pump was reached; and as the erection proceeded, this half span, like the west one, became unadjustable. When the half spans met at the center they were so nearly the same elevation that little difficulty was met in driving the center pins of the upper chords which closed the span and completed the connection between the upper chords and the web systems.

To supply the place of the end adjustments ordinarily provided for swinging the span, the Chief Engineer decided to depend mainly on expansion by temperature to extend the upper chord, and on a toggle joint to shorten the lower chord, so that the adjustment pins could be withdrawn. For one full-truss panel of the lower chord there were substituted two lengths of eye-bars connected to adjoining sections of bottom chord by temporary pins, and to each other by short coupling bars. A short vertical rod 2 ins. square, having a nut at the lower end and an eye at the upper end, passed between each pair of coupling bars and through a washer which took bearing on the lower edge of the coupling bars. The toggle joint was completed by lifting on the 2-in. square rods. The eye-bars and couplings were planed to permit the insertion of the riveted lower chord sections after swinging the span, the top-flange angles being removed and riveted back again after placing. The arrangement of the bars is shown on Plate XIX. The eye-bars were called the toggle bars; the joint at center was called the toggle joint, and the rods by which the toggle joint was pulled up were called the toggle rods.

As the ends of the half spans were too high, the opening in the lower chord between the ends of the riveted sections (one section at the center being left out), when the joints in the upper chord were just brought into bearing, was nearly 4 ins. less than the length of the closing section. It was necessary to raise the toggle joint 3 ft. before the toggle bars became taut. By loading the adjoining cantilever arms the lower chords were compressed so that the toggle bars became taut when the toggle joint was lifted 1¼ ft.

The erection of the east half-span ready for the closing sections was completed April 8th; the traveler and all superfluous material were removed; a derrick was erected on the end of each arm to handle the closing sections. The season was well advanced, and for several days the temperature had been too high to close the upper chord sections, if all preparation had been made; but cooler weather came opportunely, and at 9 A.M. of April 10th they were inserted, with an opening of only $\frac{1}{16}$ in. more than required.

During the next three days the inclined rods (Plate XIX) for lifting the toggles were placed; in addition, two pairs of heavy triple blocks, rove with manilla line 2 ins. in diameter, were placed in each truss, connecting the upper and lower chords at the center of the span, each pair of blocks having a capacity of 25 tons. The derricks were taken down, and all was in readiness to swing the span; but the weather became cold when heat was wanted.

During the swinging of the span changes in strain causing changes in length must occur. The total shortening thus caused in the upper chords amounted to about $4\frac{5}{8}$ ins. The distance between the fixed points on Piers I and III was 1 411 ft. $5\frac{1}{2}$ ins. The change in length for 1° Fahr. was 0.0095 ft. To produce a change in length of $4\frac{5}{8}$ ins. required a change of 41°. The top chord at the center of the intermediate span became closed at 56°. A temperature of 97° was necessary to release the adjustment pins in the upper chord. This natural temperature could not be had, and various means were tried to swing the span at a lower one, all tending to increase the length of the upper chord.

During the several days of cool weather which followed the connection of the top chords at the center of the span, the cantilever arms between Piers I and II were loaded with timber, rails, locomotives, etc. to about 6 000 lbs. per linear foot. The toggle rods were screwed up daily and the adjustment pins watched closely, but there was no sign of loosening. The resident engineer, Mr. Alfred Noble, adopted the expedient of heating the upper chord of the intermediate span with steam. A $1\frac{1}{2}$-in. pipe was placed in each chord for the entire length of the span. Canvas was placed under the pipe on the lacing, to retain the heated air in the chord; on the 19th of April steam from the locomotives was turned on the pipes, the toggle rods were screwed up, and as heavy a strain as they would stand was put on the lines, and blocks placed to assist in raising the toggle joint. As the tem-

perature approached its maximum for the day it was found that Pier I and III were being pushed apart, the movement of Pier I being ¼ in. and of Pier III 1¼ ins.; the possibility of this motion had been considered, both in its effects on the masonry of the piers and in swinging the span. Masonry, like all the other construction, is elastic; the piers could move much more than these amounts without injury. The motion of the piers, however, worked against the shortening of the top chord by compression, and this attempt to swing the span failed. It almost succeeded, however, as was shown by the fact that some of the upper chord web bearings could be moved on the pins.

During the next two days four rods, each 1¾ ins. round, were placed in each truss, to connect the toggle joints with the center of the upper chord and aid in lifting the toggles; steam pipes were laid in the upper chords of the central span extending half way from Pier II to Pier III. Clamps (shown on Plate XIX) were placed at the adjustment points in each of the upper chords at the west end of the intermediate span; each clamp consisted of four rods, 2½ ins. diameter, with upset ends and nuts, bearing against pieces of rail and through oak blocks bearing against the edges of the tie plates of the chord sections.

On the morning of April 22d the operation of lifting the toggle joints began; there were 24 toggle rods, and the work of turning up the nuts required several hours of steady work; the joint was finally raised 3.75 ft. above the line of the lower chord. At 4 P.M. the steam pipes were connected to the locomotives and a heavy strain put on the clamps; in an hour the adjustment pins at the west end of the upper chords became loose and were taken out; the adjustment wedges in the upper chord at the east end of the span were loosened; the upper chord being now released at both ends, all difficulties were over and the span was practically swung. Night had come, and work was suspended until morning, when the hydraulic jacks in the lower chord at the east end of the span were slackened off and taken out, the wedges were removed, the castings in both chords at the west end of the span taken out and the pins put back in place. The toggle rods and lines were then slacked off, allowing the lower chord to assume its normal position, and the permanent sections of bottom chord were inserted.

During the erection and swinging of the intermediate span the

adjoining cantilever arms had been subjected to strains exceeding those due to the loading assumed in proportioning the members, but not exceeding safe limits. Twelve days were spent in swinging this span.

The erection of the channel span completed the continuous superstructure of the Memphis bridge. The floor system was put in, the riveting was continued, and the entire structure was ready for the passage of trains on the 12th of May, when the bridge was formally opened.

Deck Span.—The deck span at the west end of the bridge does not properly belong to this paper. It is a single triangular truss consisting of six panels, the floor being sustained at the half panel points by vertical posts. The only peculiarity about this truss is the fact that at the east end the support is taken in niches at the west side of Pier IV, the posts being shortened to fit these niches and the bottom chord brought upward to a connection with the post. The floor is kept uniform throughout, the east pair of stringers connecting with the floor beam over the center of Pier IV. At the west end the full depth of the truss is maintained, and an expansion bearing on rollers similar to those on Pier II is used.

Weights.—The following table gives the weight of the superstructure classified by spans. In this table the vertical posts over Piers I, II and III, and the supports on the piers, are divided between adjacent spans :

	Pounds.
East Approach	66 812
Anchorage Span	1 606 727
Cantilever Pier I	1 252 365
East Intermediate Span	2 329 759
Cantilever Pier II	1 284 674
Central Span	5 122 252
Cantilever Pier III	1 260 452
West Intermediate Span	2 327 845
Deck Span	1 072 951
	16 323 837

These are the actual shop weights, and the sum is the total amount of metal in the bridge.

The following table gives the weights as divided in estimating the strains. The portions directly over the piers, which are carried by the piers instead of by any portion of the trusses, are eliminated from the weights of the spans :

	Pounds.
Approach from Abutment to Anchorage Pier, including fence	66 812
Anchor rods and plates in Anchorage Pier	74 995
Anchorage bars, blocks, etc., below lower chord	57 936
Tetrapod and castings	6 777
Anchorage Span, exclusive of posts Lo Uo and castings on Pier I	1 305 084
Posts Lo Uo, portal between same and castings on Pier I	323 869
East Cantilever Arm	1 090 431
East Intermediate Span	2 329 759
Cantilever Arm, Pier II	1 090 430
Posts Lo Uo, portal for same, rollers, etc., and castings on Pier II	388 489
Central Span, exclusive of end posts, castings, etc.	4 757 987
Posts Lo Uo, portal for same, castings, etc., on Pier III	340 041
Cantilever Arm, Pier III	1 090 431
West Intermediate Span, exclusive of castings	2 269 340
Castings on top of Pier IV	58 505
Deck span castings in niches of Pier IV	11 262
Deck Span, exclusive of end supports and posts Lo Uo W	1 019 664
Castings Pier V and posts Lo Uo W	42 025
Total	16 323 837

The weights per foot referred to in this paper are calculations on the basis of this table.

These several tables give the weight of the steel in the structure. The weight of the wooden floor is additional, and was estimated at 630 lbs. per linear foot, this including rails and connections.

APPENDIX A.

KANSAS CITY AND MEMPHIS RAILWAY AND BRIDGE COMPANY.

Specifications for Superstructure of Bridge across the Mississippi River, at Memphis, Tennessee.

I.—GENERAL DESCRIPTION.

1. The superstructure is divided into two parts : First, the continuous superstructure of the main bridge ; second, the deck span at the west end.

2. The continuous superstructure will consist of a central span (resting on Piers II and III), 621 ft. 0½ in. long, from each end of which will project a cantilever arm, 169 ft. 4½ ins. long ; of an anchorage span (from the anchorage pier on the Tennessee shore to Pier I), 225 ft. 10 ins. long, from which will project a cantilever arm precisely like those projecting from the central span ; of two intermediate spans 451 ft. 8 ins. long (one of which will be suspended from the cantilever arms projecting from Piers I and II, and the other will be suspended at the east end from the cantilever arm projecting from Pier III and will rest at the west end on Pier IV), the entire continuous superstructure being 2 258 ft. 4 ins. long, divided into one span of 225 ft. 10 ins., one of 790 ft. 5 ins., and two of 621 ft. 0½ in.

3. This continuous superstructure will be rigidly fastened to Piers I, III and IV, but will rest on expansion rollers on Pier II. Slip joints will be provided for expansion at the suspended ends of the independent spans.

4. The trusses will be placed 30 ft. between centers, and will be divided into panels 28 ft. 2¾ ins. long, the right being reserved to shorten the panels by an amount not exceeding ½ in. at any time before the work is actually manufactured.

5. The deck span at the west end will be 338 ft. 9 ins. long from the center of Pier IV to the center of the pin on Pier V, divided into 12 panels of 28 ft. 2¾ ins. each, the trusses being placed 22 ft. between centers. The east end of the span will be carried in niches on the west side of Pier IV; the west end will have roller bearings over the center of Pier V. This span will include a vertical bent which will carry the west end of the west pair of stringers.

6. The estimated approximate weight of the continuous superstructure is 13 000 000 pounds ; that of the deck span, 1 000 000 lbs., making the total estimated weight of the superstructure of the bridge proper, 14 000 000 lbs.

Plans.

7. Full detail plans showing all dimensions will be furnished by the engineer. The work shall be built in all respects according to these plans. The contractor, however, will be expected to verify the

correctness of the plans, and will be required to make any changes in the work which are necessitated by errors in these plans, without extra charge, where such errors could be discovered by an inspection of the plans.

II.—MATERIAL.

8. All parts, except nuts, swivels, clevises and wall pedestal plates, will be of steel. The nuts, swivels and clevises may be of wrought iron, but shall have sufficient strength to break the bodies of the members to which they are attached. The pedestal plates will be of cast iron.

9. All material shall be subject to inspection at all times during its manufacture, and the engineer and his inspectors shall be allowed free access to any works in which any portion of the material is made. Timely notice shall be given to the engineer, so that inspectors may be on hand.

Steel.

10. Steel will be divided into three classes: First, High-Grade Steel, which shall be used in all the principal truss members; second, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; third, Soft Steel, which shall be used only for rivets, and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of cast steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel may be made by the open-hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus, and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the Chief Engineer.

15. In the finished product of open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{10}$ of 1 per cent.

16. In the finished product of Bessemer steel, the amount of phosphorus shall not average more than $\frac{4}{100}$ of 1%, and never exceed $\frac{1}{20}$ of 1 per cent.

17. A sample bar $\frac{3}{4}$ in. in diameter shall be rolled from every melt, the method of obtaining the piece from which this bar is rolled to be the same in all cases, and the amount of work on this sample bar to be as nearly as practicable the same as on the finished product. The first laboratory test shall be made on this sample bar in its natural state without annealing.

18. A second sample bar having a cross-section of 1 sq. in. shall be cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180° and closed up against itself without showing any crack or flaw on the outside of the bent portion.

21. The first laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.....	71 500	65 500	57 000
Minimum Elastic Limit, lbs. per sq. in.....	42 000	38 000	32 000
Minimum percentage of Elongation in 8 ins.....	20	24	28
Minimum percentage of Reduction at Fracture.....	40	45	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.....	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.....	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.....	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.....	18	22	28
Minimum percentage of Reduction at Fracture.....	38	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected.

25. A full report of the laboratory tests shall be furnished, certified by an inspector accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Three notices of the acceptance of each melt shall be mailed on the day of such acceptance, stating the number of the accepted melt and quality of steel. Two of these notices shall be sent to the Chief Engineer at his Chicago and New York offices respectively; and one to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese, and certified copies of these analyses shall be furnished to the mill inspector, who will forward them to the Chief Engineer.

29. Weekly reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office not later than the end of the week succeeding the week in which such tests are made.

30. Three notices of the shipment of manufactured material identifying the melts and dimensions shall be mailed on the day after such shipments are made, in the same manner as the notices of acceptance of material.

31. Every finished piece of steel shall be stamped on one side near the middle of the bar and also on both ends of the bar with a number, identifying the melt.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-sections shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be drilled through the axis.

CAST STEEL.

36. A sample bar 1¼ ins. in diameter and 16 ins. long shall be cast from every melt. This sample bar shall then be turned down to ¾ in. in diameter and the laboratory tests made upon it.

37. These laboratory tests shall show an ultimate strength of at least 70 000 lbs., an elastic limit of at least 40 000 lbs. and an elongation of at least 15% in 8 ins. and a reduction of 18% at point of fracture.

38. Steel castings shall be sound and as free as possible from blow holes.

39. If on the finished surface the blow holes cover more than $\frac{1}{1000}$ part of the entire surface, and if any blow hole exceeds ⅛ in. in diameter, the casting shall be rejected.

CAST IRON.

40. Cast iron shall be the best quality of dark gray charcoal iron of a quality suitable for car wheels, the castings to be entirely sound and free from blow holes.

III.—MANUFACTURE.

41. The work shall be done in all respects according to the detail plans furnished by the Chief Engineer.

42. Where there is room for doubt as to the quality of work required by the plans or specifications, the doubt shall be decided by using the best class of work which any interpretation would admit of.

43. All workmanship, whether particularly specified or not, must be of the best kind now in use. Past work done for the same chief engineer will never be recognized as a precedent for the use of other than the best kind of work.

44. Ragged edges or any kind of irregularities or unnecessary roughness will be sufficient ground for rejection.

45. All surfaces in contact shall be cleaned and painted before they are put together.

46. All work shall be finished in the shop and ample time given for inspection.

47. No material shall be loaded on cars until accepted by the inspector.

48. The finishing of work after loading will not be permitted.

SOLID DRILLED WORK.

49. All riveted members which are made of High-Grade Steel and all other pieces connecting with such members shall be solid drilled, no punching whatever being allowed, excepting lacing bars which may be punched and reamed.

50. All plates, angles and shapes shall be carefully straightened at

the shops before they are put together. Mill straightening will not be considered to meet this requirement.

51. The pieces shall be then assembled and held in position by clamps and bolts.

52. Where bolts passing through the metal are used, the holes shall be drilled in all metal more than $\frac{3}{4}$ in. thick, the diameter of the drilled hole to be at least $\frac{1}{8}$ in. less than the diameter of the finished hole.

53. In metal not more than $\frac{3}{4}$ in. thick, punched holes may be used for fitting up, the diameter of the punched hole not to be more than three-quarters the diameter of the finished hole, and the number of punched holes never to exceed eight in any one plate or four in one flange of any one angle.

54. After assembling, the work shall be drilled, the rivet holes being carefully spaced in truly straight lines and at the exact distances shown on the plans.

55. After the drilling is completed, a special reamer shall be run over both edges of every hole, so as to remove the sharp edges and make a fillet of at least $\frac{1}{16}$ in. under each rivet head.

56. The assembled parts shall then be riveted up without taking apart, unless specially directed by the Chief Engineer.

57. In general, all holes which are to pass through several thicknesses of metal shall be drilled with all those pieces of metal assembled in the exact relative position they are to hold in the bridge.

58. In the case of connections between members having four webs, one member may be finished complete with the splice plates riveted on. The two inside webs of the adjoining member, one end being already faced, may then be fitted up separately in their true position and the rivet holes in the splices drilled. These inside webs may then be removed; the member to which they belong shall be assembled, riveted up complete and the ends faced, the facing to agree exactly with the two ends already faced (see Section 67). The member shall then be fitted to the adjoining member, and the rivet holes in the splices connecting the outside web shall be drilled.

59. The size of rivets shown on the plans is the size of the cold rivet before heating.

60. The diameter of the finished hole shall not be more than $\frac{1}{16}$ in. greater than the diameter of the cold rivet. It is intended that the heated rivet shall not drop into the hole, but require a blow from a hammer to force it in. If it is found that rivets will drop easily into the holes the inspector will condemn those rivets and order a larger size.

61. In all cases where riveting is to be done in the field, the parts so to be riveted shall be fitted together in the shops and the rivet holes drilled while they are so assembled.

62. The riveted connections of the portals, cross frames and floor beams with the posts and chords shall be drilled with the several parts fitted together, excepting in the case of interchangeable floor beams.

63. An iron templet not less than 2 ins. thick may be used instead of the floor beams when drilling the holes in the chords, and the same templet instead of the chords when drilling the holes in the floor beams ; a templet may be used in the same manner in drilling the connections between the floor beam and the supported upright at panel points where two inclined members come together ; but the connection between the floor beam and the vertical suspenders at panels point L_1 and L_2 of the intermediate spans shall be drilled with the parts actually assembled, and marked. With this arrangement two floor

beams at each end of the intermediate spans, making eight in all, become special ; the other floor beams are classed as interchangeable.

64. All rivets shall be driven by power wherever this is possible.

65. All rivets shall be regular in shape, with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed. This applies to both power-driven and hand-driven rivets.

66. All pin holes and holes for turned bolts passing through the whole width of a riveted member shall be bored or drilled after all other work is completed.

67. All surfaces in contact shall be carefully faced, the facing to be done after the entire member is assembled and riveted up except that in the case of chord sections with four webs the inside webs may have one end faced before they are assembled, these two faced ends to be carefully held against a plane surface when assembled and the corresponding ends of the other two webs to be faced after riveting and to agree with the ends already faced.

68. When two chord pieces are fitted together complete in the shop there shall be no perceptible wind in the length of the two sections. The chords are generally made in two panel lengths, or 56 ft. 5½ ins. long. In the case of shorter lengths a sufficient number of pieces shall be put together to make a continuous length equal to two of the long sections.

69. All chord sections shall be stamped at each end on the outside with letters and numbers designating the joints in accordance with the diagram plan furnished by the Chief Engineer.

70. The posts shall be fitted together for their entire length and bolted up and when so fitted shall be perfectly straight and free from wind.

71. The same rule shall apply to the marking of the posts as to the marking of the chords.

72. Pin holes shall be bored truly and at exact distances parallel with one another and at exactly right angles to the axis of the member.

73. Pin holes in the posts shall be truly parallel with one another and shall be at right angles to the axis of the post.

74. Pin holes shall be bored with a sharp tool which will make a clean, smooth cut. Two cuts shall always be taken, the finishing cut never to be more than $\frac{1}{8}$ in. Roughness in pin holes will be sufficient reason for rejecting a whole member.

75. Measurements shall be made from an iron standard of the same temperature as the member measured.

PUNCHED AND REAMED WORK.

76. All riveted members which are composed entirely of Medium Steel may be punched and reamed, but this does not apply to the connections between such members and High-Grade Steel members, which connections shall be solid drilled throughout.

77. All plates, angles and shapes shall be carefully straightened at the shops before they are laid out. Mill straightening will not be held to meet this requirement.

78. The rivet holes shall be marked from templets and these templets shall lie flat without distortion when the marking is made.

79. The angles of stringers must be square and straight. The web plate must not project above the angles and the top surfaces of the

top angles must be such that the outside edges are never above a true plane and never more than $\frac{1}{16}$ in. below a true plane coincident with the roots of the angles.

80. The outside angle at the root of the angles connecting the stringers with the floor beams or the floor beams with the posts, chords or other members, shall never be less than a right angle, and the excess over a right angle shall never be greater than $\frac{1}{8}$ in. in the longer leg of the angle; the angle shall be perfectly straight.

81. In fitting these angles to stringers or floor beams they shall be so fitted that the exact length is measured to the root of the angle, the two roots being in exactly the same plane; the entire end of the assembled member shall then be faced. The effect of these requirements will be to prevent any reduction of area of the angle at the root by facing and to secure a true surface of the whole width of the connection which will require no strain in the rivets to draw the parts together.

82. After laying out with templets, the rivet holes may be punched with a punch at least $\frac{3}{32}$ in. smaller than the diameter of the rivets as given on the plans, and working in a die only $\frac{1}{64}$ in. larger than the punch.

83. The several parts of the member shall then be assembled and the holes reamed so that at least $\frac{1}{16}$ in. of metal is everywhere taken out.

84. After the reaming is completed, a special reamer shall be run over both edges of every hole so as to remove the sharp edges and make a fillet of at least $\frac{1}{16}$ in. under each rivet head.

85. The pieces shall be riveted together without taking apart.

86. All requirements as to size and quality of rivets and manner of riveting and measuring shall be the same as the requirements for solid drilled riveted work.

87. All bearing surfaces shall be truly faced.

88. All sheared edges shall be planed off and all punched holes shall be drilled out so that none of the rough surface is ever left upon the work.

FORGED WORK.

89. The heads of eye-bars shall be formed by upsetting and forging into shape by a process acceptable to the Chief Engineer. No welds will be allowed.

90. After the working is completed, the bars shall be annealed in a suitable annealing furnace by heating them to an uniform dark red heat and allowing them to cool slowly.

91. The form of the heads of the steel eye-bars may be modified by the contractors to suit the process in use at their works, but the thickness of the head shall not be more than $\frac{1}{16}$ in. greater than that of the body of the bar, and the heads shall be of sufficient strength to break the body of the bar.

92. The heads and the enlarged ends for screws in laterals, suspenders and counters shall be formed by upsetting and shall be of sufficient strength to break the body of the bar.

93. Nuts, swivels and clevises, if made of steel, shall be forged without welds; whether made of steel or wrought iron, one of each size shall be tested and be of sufficient strength to break the bars to which they are attached.

94. Eye-bars shall be bored truly and at exact distances, the pin

holes to be exactly on the axis of the bar, and at exactly right angles to the plane of the flat surfaces.

95. When six bars of the same billed length are piled together, the two pins shall pass through both pin holes at the same time without driving. Every bar shall be tested for this requirement.

96. Pin holes shall be bored with a sharp tool that will make a clean, smooth cut. Two cuts shall always be taken, the finishing cut never to be more than $\frac{1}{8}$ in. Roughness in pin holes will be sufficient reason for rejecting bars.

97. Twenty full-sized steel eye-bars shall be selected from time to time from the bars made for the bridge by the inspector for testing.

98. No bars known to be defective in any way shall be taken for test bars, but the bars shall be selected as fair average specimens of the good bars which would be accepted for the work.

MACHINE-WORK.

99. All bearing surfaces shall be faced truly.

100. Chord sections and half-post sections shall be faced after they are riveted up complete, the facing to be perfectly true and square. In the case of four web chords, one end of the two inside webs only may be faced before riveting up.

101. The ends of the stringers and of floor beams shall be squared in a facer.

102. All surfaces, so designated on the plans, shall be planed.

103. All sheared edges shall be planed off, and all punched holes shall be drilled or reamed out.

104. All pins shall be accurately turned to a gauge, and shall be of full size throughout.

105. Pin holes shall be bored to fit the pins with a play not exceeding $\frac{1}{50}$ in. These requirements apply to lateral connections as well as to any other pins.

106. The plans show the distances between centers of pin holes. Shop measurements, however, shall be made between the bearing edges of the pin holes, that is, between the inside edges of compression members and the outside edges of tension members, with a proper allowance for the diameter of the pin. An iron standard of the same temperature as the piece measured shall always be used.

107. All screws shall have a truncated V thread, United States standard sizes.

108. Special pains shall be taken with the roller bearings on Pier II. The castings shall be accurately fitted together, and when bolted up the top surface shall be a perfectly true plane.

109. The rail plates shall be planed on the bottom after being riveted up, then planed on the top, and the surface polished. Any roughness or irregularity which prevents an uniform opening between the rail heads shall be planed out.

110. The rollers shall have the hollow sides planed, and the bearing surfaces turned to a perfectly true cylinder and polished.

111. The rods passing through the rollers shall fit the holes with a play not exceeding $\frac{1}{32}$ in.

112. The side bars connecting the rods shall be drilled to fit the rods with a play not exceeding $\frac{1}{32}$ in., and the upper and lower surfaces of these side bars shall be planed.

113. The lower side bar in each instance shall be fitted with a graduated bronze scale, so divided as to register inches of motion of the top

bearing, and the upper bar shall be fitted with a German-silver vernier, so divided as to read to sixteenths of inches as graduated on the scale.

114. The two bearings, including everything between the masonry and the 14-in. pin, shall be set up complete in a level position at the Athens shops, and shall not be shipped before they have been examined and approved by the Chief Engineer. They shall be ready for his inspection on or before January 1st, 1891.

115. Special pains shall be taken with the slip joints at the suspended ends of the intermediate spans; the surface of the joints shall be polished and fitted exactly.

MISCELLANEOUS.

116. All material shall be cleaned, and, if necessary, scraped and given one heavy coat of Cleveland iron-clad paint, purple brand, put on with boiled linseed oil, before shipment. This applies to everything except machine-finished surfaces.

117. The same paint shall be used wherever painting is required.

118. All machine surfaces shall be cleaned, oiled, and given a heavy coat of white lead and tallow before shipment. The inspector must see that this is a substantial coat, such as is used on machinery, and not a merely nominal covering.

119. All small bolts, all pins less than 6 in. in diameter, the expansion rollers, and everything with special work on it, shall be carefully boxed before shipment.

120. The contractor will be required to furnish the field rivets for erection, furnishing 20% in excess of each size over and above the number actually required, but this excess will not be estimated, but considered as taking the place of the work which is not done on these rivets.

V.—INSPECTION.

121. The mill inspection shall be performed at the expense of the contractor by an inspector accepted by the Chief Engineer.

122. This inspector will be required to furnish the certificates and notices in the manner specified above.

123. The mill inspector shall from time to time check the manufacturers' analyses by analyses made by an independent chemist.

124. The acceptance of material by such inspector will not be considered final, but the right is reserved to reject material which may prove defective or objectionable at any time before the completion of the contract.

125. The inspection at the shops will be under the charge of an inspector appointed by the Chief Engineer, with such assistants as may be required.

126. Such inspector will be considered at all times the representative of the Chief Engineer, and his instructions shall be followed in the same manner as if given by the Chief Engineer.

TESTS OF FULL-SIZED BARS.

127. The test of full-sized eye-bars shall be made in the large testing machine at Athens.

128. These bars will be required to develop an average stretch of 12%, and a minimum stretch of 10%, before breaking. The elongation shall be measured on a length of not less than 20 ft., including the fracture.

129. The bar will be required to break in the body.

130. They shall also show an elastic limit of not less than 32 000 lbs., and an ultimate strength of not less than 62 000 lbs., as indicated by the registering gauges of the testing machine at Athens.

131. In the case of bars too long for the machine, the bars shall be cut in two, each half reheaded, and both halves tested in the machine, the two tests, however, to count as a single test bar.

132. If the capacity of the machine (estimated at 1 200 000 lbs.) is reached before the bar is broken, the bar shall be taken out of the machine and the edges shall be planed off for a length of 10 ft. at the center until the section is reduced to the equivalent of 16 sq. ins. of section of the original bar. The bar shall then be placed in the machine and broken ; when this is done, the elongation shall be measured on a length of 8 ft. and an ultimate strength of 60 000 lbs., computed on the 16 ins. of original section will be considered satisfactory.

133. In these tests, a failure to meet the required elongation will be considered fatal, and be a sufficient cause for condemning the bars represented by the bar so tested; but the Chief Engineer shall examine carefully into the cause of the breakage of any bar which does not meet the requirements, and may order additional tests if he sees fit.

134. The failure of a bar to break in the body shall not be considered sufficient reason for rejection, provided the required elongation is obtained and not more than one-quarter of the bars break in the head.

135. In all requirements and tests the quantities given are minimum or maximum requirements, and not averages unless expressly so stated.

V.—TERMS.

136. The work will be paid by the pound of finished work loaded on cars at Buffalo.

137. On riveted work and other material shipped from Athens, the difference between the freight rates from Athens to Memphis and from Buffalo to Memphis will be borne by the contractor.

138. No material will be paid for which does not form a part of the finished superstructure.

139. All expenses of testing shall be borne by the contractor.

140. All riveted work shall be manufactured at the Athens shop, unless by special permission of the Chief Engineer.

141. Prices will be per pound at separate rates for High-Grade Steel and for Medium Steel.

142. To avoid complications, all members, the principal parts of which are High-Grade Steel, shall be estimated as wholly of High Grade Steel, and all members, the principal parts of which are of Medium Steel, shall be estimated as wholly of Medium Steel.

143. Cast Steel shall be estimated as High-Grade Steel.

144. Cast and wrought iron shall be estimated at the same price as Medium Steel.

145. The anchorage span, the east cantilever arm and one-half the east intermediate span shall be completed and shipped on or before October 1st, 1890.

146. The deck span shall be completed and shipped on or before December 1st, 1890.

147. The central span and the two adjoining cantilever arms shall be shipped complete on or before June 1st, 1891.

148. The west intermediate span and the second half of the east in-

termediate span shall be shipped complete on or before August 1st, 1891.

149. Approximate estimates shall be made at the end of each month of the material received and work performed up to that time.

150. In these estimates material received at the shops, but not manufactured, shall be estimated at 65% of the contract price for finished material.

151. Material manufactured, but not shipped, shall be estimated at 85% of the contract price.

152. Material completed and shipped shall be estimated at the full contract price.

153. Payments shall be made on these estimates on or about the middle of the following month, deducting therefrom 10%, which shall be held as security until the completion of the entire contract.

154. In these monthly estimates no material will be estimated as received at the shop more than six months before the date set for the completion and shipment of such material.

155. In these monthly estimates no material will be estimated as manufactured more than four months before the date set for the completion and shipment of such material.

156. The contractors will be required to keep the material at their shops insured from injury by fire to the full amount of the payments made on such material by the Bridge Company.

VI.—ERECTION.

157. The contractor will be expected to receive all material as it arrives on the cars, to unload this material and store it in a material yard until ready for erection.

158. He will be held responsible for the custody and care of all superstructure material after its arrival.

159. The material of the main continuous superstructure will be delivered on cars on the east side of the river.

160. When ready for erection, the Bridge Company will switch any cars on which this material has been loaded, to a point where it can be transferred to barges, no charge being made for such switching.

161. All material for the deck span at the west end will be delivered on cars on the west side of the river.

162. A track will be laid to a convenient position for unloading material near Pier V, and no switching will be done after the material has once been unloaded.

163. The contractor will be required to keep all the material in good condition, and in case of its becoming dirty or rusty will be expected to clean it before erecting.

164. The contractor will be required to paint all surfaces which will be inaccessible for painting after erection, the paint being furnished by the Bridge Company.

165. The contractor will be required to furnish all tools, barges and false-work of every description, excepting power riveters.

166. The contractor will be required to remove all work which he may put in the river so that there will be nothing left either to interfere with navigation or to catch drift.

167. No holes shall be drilled or bolts placed in the piers without the express permission of the Engineer.

168. All bolts so put in shall be removed and the holes carefully

filled with Portland cement mortar, and any damages done shall be charged to the contractor.

169. The contractor will be required to erect the superstructure complete in every respect, including riveting.

170. Everything is to be completed ready to receive the timber floor.

171. The erection shall include the placing and riveting of the iron hand rail.

172. The contractor will be expected to raise the ties for the central span and the adjoining cantilever arms, and distribute them without charge. This does not include any framing, fitting or bolting. The ties will be delivered to the contractor loaded on barges.

173. The central span will be raised on false-work.

174. The west intermediate span will be raised on false-work.

175. The east intermediate span may be raised on false-work, or without, at the option of the contractor.

176. The anchorage arm east of Pier I will be raised on false-work.

177. The three projecting cantilever arms will be built out without false-work.

178. It is expected that the anchorage arm and the cantilever arm projecting from Pier I can be raised in the fall of 1890. That the deck span at the west end can be raised in the following winter. That the false work for the central span can be put in in August and September of 1891, and the erection of this span completed in the following month. That the cantilevers can be built out and the entire bridge completed by January 1st, 1892.

179. All erection shall be done under the direction of the Chief Engineer and in conformity with his requirements.

180. The wall plate castings shall be set on Piers II and III before the bottom chord is placed.

181. The expansion rollers and the bolster complete shall be set on Pier III. The bottom chords shall then be put together and riveted up complete. The expansion end shall then be adjusted so that the axis of the rollers will be exactly vertical at a temperature of 70° Fahr. This adjustment shall be made at a time when there has been no sun on the steelwork for 10 continuous hours, and when there has been no sudden change of temperature. The span shall be erected complete and the end rollers shall be examined again, and if any error is found, it shall be corrected, the correction being made under the same conditions as to sunshine and sudden changes of temperature as the original adjustment. Special care shall be taken with the rollers while the span is being swung, and if by any accident they get out of place, the span shall be wedged again, and the rollers be readjusted.

182. The eye-bars in the end panel of the top chord shall be stiffened so as to resist compression by fitting planks between the bars and bolting the whole together.

183. When the erection of the central span is completed, the two cantilever arms shall be built out, and the two intermediate spans erected, thus completing the bridge.

184. All rivets shall be regular in shape with hemispherical heads concentric with the axis and absolutely tight. Tightening by calking or recupping will not be allowed.

185. All riveted joints which have to resist tension, this including all joints in both chords of the central span and all joints in the bottom chord of the intermediate spans shall be riveted by power, except in such special cases as the engineer may authorize hand-driven rivets. This authority will never be given for rivets in splices of web-plates.

186. A power riveter, with air pump or with hydraulic pump and accumulator will be furnished by the Bridge Company. The contractor will be required to keep the same in repair and will not be relieved from any responsibility in this connection, the Bridge Company only agreeing to bear the cost of the machine.

187. No extra bills are to be rendered by the contractor, except for new work not embraced in the contract. Charges for reaming holes, fitting bolts in place of rivets and other small work of this class will not be allowed.

188. The setting of the wall plate castings, including the drilling of holes in masonry for the anchor bolts, the packing of rust cement or lead under the castings, and all other work connected therewith, is to be done by the contractor.

189. The contractor will be responsible for any damages which the Bridge Company may be held liable for in consequence of any of his work.

GEORGE S. MORISON,
Chief Engineer.

JANUARY 4TH, 1890.

APPENDIX B.

MODIFICATIONS OF SPECIFICATIONS FOR SUPERSTRUCTURE OF BRIDGE ACROSS THE MISSISSIPPI RIVER, AT MEMPHIS, TENN., ACCEPTED APRIL 22D, 1890.

STEEL.

10. Steel will be divided into three classes: first, High-Grade Steel, which shall be used in all the principal truss members; second, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; third, Soft Steel, which shall be used only for rivets and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of Cast Steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel shall be made by the open-hearth process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus, and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the chief engineer.

15. In the finished product of acid open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{100}$ of 1 per cent.

16. In the finished product of basic open-hearth steel, the amount of phosphorus shall not average more than $\frac{6}{100}$ of 1%, and never exceed $\frac{7}{100}$ of 1 per cent.

17. A sample bar $\frac{3}{4}$ in. in diameter shall be rolled from a 4-in. ingot cast from every melt. The first laboratory test shall be made on this sample bar in its natural state without annealing.

18. A second sample bar having a cross-section of 1 sq. in. shall be

cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180°, and closed up against itself without showing any crack or flaw on the outside of the bent portion. Two successful tests out of a total of three will be accepted as satisfactory.

21. The first laboratory test shall meet the following requirements:

	High-Grade and Medium Steel.	Soft Steel.
Minimum Ultimate Strength, lbs. per sq. in	65 000	57 000
Minimum Elastic Limit, lbs. per sq. in	38 000	32 000
Minimum percentage of Elongation in 8 ins	20	28
Minimum percentage of Reduction at Fracture	40	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in	78 500	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in	69 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in	40 000	37 000	30 000
Minimum percentage of Elongation in 8 ins	18	22	28
Minimum percentage of Reduction at Fracture	38	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected. Cases in which the tests are thought not to give fair representations of the character of the material shall be referred to the Chief Engineer.

25. A full report of the laboratory tests shall be furnished, certified by an inspector accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Three notices of the acceptance of each melt shall be mailed on the day of such acceptance, stating the number of the accepted melt and quality of steel. Two of these notices shall be sent to the Chief Engineer at his Chicago and New York offices respectively, and one to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese and certified copies of these analyses shall be furnished to the mill inspector who will forward them to the Chief Engineer. The phosphorus and carbon

analyses shall always be made. Analyses for silicon and manganese shall be made whenever called for by the inspector. Copies of all analyses, whether made by request of the inspector or by the desire of the manufacturer, shall be furnished to the Chief Engineer.

29. Weekly reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office not later than the end of the week succeeding the week in which such tests are made.

30. Three notices of the shipment of manufactured material, identifying the melts and dimensions, shall be mailed on the day after such shipments are made, in the same manner as the notices of acceptance of material.

31. Every finished piece of steel shall be stamped on one side near the middle of the bar, and also on both ends of the bar, with a number identifying the melt. If it is found impossible to stamp any particular piece on the ends, the inspector may authorize the two end stamps to be put on the surface within $\frac{1}{2}$ in. of each end, the fact of the stamping being done in this way to be specified distinctly on all notices and invoices; this may be done, however, by an agreed character.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-sections shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be annealed before they are turned and shall be drilled through the axes.

GEORGE S. MORISON,
Chief Engineer.

MAY 6TH, 1890.

APPENDIX C.

MODIFICATIONS OF SPECIFICATIONS FOR SUPERSTRUCTURE OF BRIDGE ACROSS THE MISSISSIPPI RIVER AT MEMPHIS, TENN., ACCEPTED DECEMBER 29TH, 1890.

STEEL.

10. Steel will be divided into four classes: first, High-Grade Steel, which shall be used in all the principal truss members except eye-bars; second, Eye-Bar Steel, which shall be used only in eye-bars; third, Medium Steel, which shall be used in the floor system, laterals, portals, transverse bracing and lacing of the truss members; fourth, Soft Steel, which shall be used only for rivets, and at the option of the contractor where wrought iron is permitted.

11. The bolsters which carry the large pin bearings on Piers I, II and III shall be of cast steel.

12. In any case where it seems doubtful what quality of steel is required, High-Grade Steel shall be used.

13. Steel shall be made by the open-hearth process, but no steel shall be made at works which have not been in successful operation for at least one year.

14. All steel shall be made from uniform stock low in phosphorus,

and the manufacturer shall furnish reports of the analysis of every melt, certified by a chemist satisfactory to the Chief Engineer.

15. In the finished product of acid open-hearth steel the amount of phosphorus shall not average more than $\frac{8}{100}$ of 1%, and never exceed $\frac{1}{10}$ of 1 per cent.

16. In the finished product of basic open-hearth steel the amount of phosphorus shall not average more than $\frac{6}{100}$ of 1%, and never exceed $\frac{7}{100}$ of 1 per cent.

17. A sample bar $\frac{3}{4}$ in. in diameter shall be rolled from a 4-in. ingot cast from every melt. A laboratory test shall be made on this sample bar in its natural state without annealing, but this test may be made subsequent to the acceptance of the material, and shall be for record only.

18. A second sample bar having a cross-section of 1 sq. in. shall be cut from the finished product of every melt. The second laboratory test shall be made on this sample bar in its natural state without annealing.

19. In the laboratory tests all observations as to elastic limit, ultimate strength, elongation and reduction shall be made on a length of 8 inches.

20. A piece of each sample bar shall be bent 180°, and closed up against itself without showing any crack or flaw on the outside of the bent portion. Two successful tests out of a total of three will be accepted as satisfactory.

21. The first laboratory test shall meet the following requirements:

	High-Grade, Eye-Bar and Medium Steel.	Soft Steel.
Minimum Ultimate Strength, lbs. per sq. in.	65 000	57 000
Minimum Elastic Limit, lbs. per sq in.	38 000	32 000
Minimum percentage of Elongation in 8 ins.	20	28
Minimum percentage of Reduction at Fracture	40	50

22. The second laboratory test shall meet the following requirements:

	High-Grade Steel.	Eye-Bar Steel.	Medium Steel.	Soft Steel.
Maximum Ultimate Strength, lbs. per sq. in.	78 500	75 000	72 500	63 000
Minimum Ultimate Strength, lbs. per sq. in.	69 000	66 000	64 000	55 000
Minimum Elastic Limit, lbs. per sq. in.	40 000	38 000	37 000	30 000
Minimum percentage of Elongation in 8 ins.	18	20	22	28
Minimum percentage of Reduction at Fracture.	38	40	44	50

23. If the ultimate strength comes within 500 lbs. of the maximum or minimum limit, a second test will be made, and both tests will be required to come within the limits.

24. Every melt which does not conform with these requirements shall be rejected. Cases in which the tests are thought not to give fair representations of the character of the material shall be referred to the Chief Engineer.

APPENDIX D.

Tests of Steel Eye-Bars.

Remarks.	Span.	Tests on full-sized Eye-Bars. Dimensions, Inches. Original. Nominal. Width.	Nominal. Thickness.	Actual. Length, c to C.	Actual. Ganged length.	Actual. Width.	Actual. Thickness.	Results of Mechanical Tests. After Test. Width.	After Test. Thickness.	Reduction of area. Percent.	Elongation. Inches.	Elongation. Percent	Elastic Limit. Lbs. per sq. in.	Max. Load. Lbs. per sq. in.	Place of Fracture.	Tests on Sample Bars from same Melt. Melt Number.	Areas. Original, Inches.	Areas. After testing, Inches.	Reduction. Percent.	Elongation. Percent	Elastic Limit. Lbs. per sq. in.	Max. Load. Lbs. per sq. in.	Phosphorus. Percent.	Kind of Steel.	Made by—	Forged by—
Flaw in back of eye	Experimental	10	1¼	160.63	120	10.07	1.50	8.00	1.14	39.6	20.2	16.8	35 100	67 480	Body	6 552	.9500	4992	47.5	27.5	41 500	73 050	.027	Basic open hearth	Carnegie, Phipps & Co.	Union Bridge Co.
High steel	"	10	1⅞	158.07	120	10.16	1.46	....	....	....	10.75	8.96	36 050	65 190	Head	6 552										
	"	10	1⅞	358.93	324	9.95	1.78	7.86	1.32	39.7	26.6	8 2	37 680	70 160	Body	10 747	.9918	4593	52.6	24 4	42 650	75 620	.045	" " "	" " "	" " "
	"	10	1¾	361.23	312	9.98	1.76	7 77	1.25	44.4	36.8	11.8	39 700	65 500	"	10 647	.9520	4057	47.9	28 8	40 280	70 280	.062	" " "	" " "	" " "
	Anchorage	10	1½	162.38	120	10.05	1.50	8 06	1.15	38.5	38.6	17.3	33 140	65 090	"	6 552	.9500	4992	47 5	27.5	41 580	73 050	.027	" " "	" " "	" " "
	"	6	1½	391.26	252	6.08	1 13	4 63	0.54	56.9	33.7	15.4	29 690	56 700	"	10 880	9756	5330	45 4	28 1	40 490	69 700	.026	" " "	" " "	" " "
Bar cut in two. Reheaded, not reannealed. First half: bar stretched to full capacity of machine, then planed to a section equivalent to 16 sq. ins. original	"	6	1½	314.18	288	6.09	1.12	4 83	0 82	41.9	39.6	13.8	30 800	59 210	"	10 830										
	"	10	1¼	287 37	240	10.07	1.67	8.07	1.25	40 0	32.5	13 5	32 860	65 600	"	09 090	1 1590	.6474	44.5	20 0	43 750	75 080	.021	" " "	" " "	" " "
	"	10	1⅛	284.28	240	9.92	1.95	7.97	1.47	39 4	36.8	15.3	31 110	61 960	"	5 798	1 0140	5814	42.7	28 8	42 240	69 730	.006	" " "	" " "	" " "
	"	10	1	287.88	240	9.94	0.99	8 05	0.80	34 6	32.9	13.7	33 090	63 220	"	10 886	.9658	4719	52.2	28 1	40 230	69 790	.025	" " "	" " "	" " "
	"	10	2⅛	223.88	96	10.05	2.20	6.69	1.77	32 6	13.0	13.5	29 330	63 100	"	015 014	.9655	.4983	48 3	28.8	38 090	71 500	.037	" " "	" " "	" " "
	"	10	2⅛	222.48	96	10.05	2.18	5.75	1.63	41 4	14 6	15.2	28 660	63 860	"	015 014	.....	.....	.....	.....	.....	.....	.....	" " "	" " "	" " "
Second half treated same as above	"	10	1½	464 03	420	10.12	1.86	9.99	1.80	4 5	10.4	2.5	31 970	53 860	"	015 000	1.0201	.6084	40.4	27 0	40 200	71 860	.017	" " "	" " "	" " "
Piping in fracture. Reheaded, not reannealed. Broke in new head. Elongation is total for both tests. Retest of above.	"	10	1⅞	198.03	144	....	....	....	....	....	4 7	3.2	.....	58 950	Head	015 000										
Soft steel suspender	"	7	1⅛	314.04	276	7 12	1.17	5.14	0.77	59.5	59.3	21.5	30 270	51 500	Body	11 045	1.0180	.4941	51.5	28.8	33 490	57 170	.014	" " "	" " "	Keystone
Foreign substance in fracture	Central	10	2⅛	338.73	300	10.07	2.20	0.73	2.11	7.3	20.8	6.9	28 080	55 160	"	11 063	1.1220	.6371	43 2	24 2	38 320	70 220	.023	" " "	" " "	Union
Retest of above. Reheaded, not reannealed. Planed to equivalent of 16 sq. ins., original area	"	10	2⅛	.....	96	....	..	5.88	1.70	37 5	18 4	19.2	.....	62 690	"	11 063										
First half of bar cut in two. Reheaded, not reannealed	"	10	1⅛	251.58	204	10.03	1 81	8.08	1 39	38.1	28.9	14 1	29 670	62 140	"	015 094	1.0200	4121	59.6	26 3	40 200	71 080	.028	" " "	" " "	" " "
Second half of above	"	10	1⅛	250.08	204	10 05	1 81	....	....	....	5.7	2.8	29 270	49 340	Head	015 094										
Above reheaded, not reannealed	"	10	1⅛	194 88	144	....	....	....	....	....	5.2	3.6	.....	53 930	"	015 094										
First half	"	10	1⅛	250.28	204	9.97	1.37	8.39	1 11	31.8	34.0	11.8	33 700	65 490	Body	015 093	1.0670	.6374	40.3	25.0	39 360	69 360	.041	" " "	" " "	" " "
Second half of above. One head buckled, rebored, and then test finished	"	10	1⅛	247.78	204	9.99	1.37	8 15	1.07	36.3	23.0	11.3	31 290	64 510	"	015 093										
Soft steel suspender	"	7	1⅛	385.78	348	7.02	1.31	5.16	0 92	48 4	78.3	22.6	28 980	52 010	"	8 368	1 1700	.5133	54.2	31.3	34 700	58 460	.030	" " "	" " "	Keystone
First half	Cantilever	7	1¼	386.78	348	7.01	1.26	5.13	0.83	51.8	47.3	13.6	28 410	54 740	"	6 961	1.0170	.5220	48.7	28.1	41 400	67 840	.010	" " "	" " "	Union
Second half. Spot of foreign matter in fracture	"	10	1⅝	349.08	204	9.99	1 62	7.49	1 11	48.6	39.4	19.3	30 600	58 870	"	40 411	.9338	.5572	40.3	25.0	40 910	70 260	.014	" " "	" " "	" " "
	"	10	1½	260.23	204	10 02	1.63	9.49	1 52	11.1	19.6	9.6	29 980	56 960	"	40 411										
Bar strained to 5 930 lbs. per square inch, then planed to equivalent of 16 sq. ins., original section. Area reduced 1 from fracture, 12 per cent.	"	10	2⅛	341.28	96	9.96	2.05	7.52	1.91	10.3	11 8	12.3	33 360	73 550	"	5 868	.9700	4792	51 5	25.5	40 410	69 900	.063	" " "	" " "	" " "
	"	10	1⅛	249.48	204	10.13	1.30	7.92	0.92	44.6	32 0	15 7	32 520	60 710	"	40 435	9504	.5363	43 6	27.0	40 400	70 490	024	" " "	" " "	" " "
	"	10	1⅛	249.58	204	10.13	1.30	7.77	0 94	44 6	35.3	17.3	31 900	59 470	"	40 435										
Second part of above	"	10	1⅛	284.82	240	9.98	1.81	7.62	1.28	46 0	35.8	14 9	28 090	58 720	"	013 091	1 0090	.5557	44 4	29.5	40 100	66 800	008	" " "	" " "	" " "
First part	"	10	1⅛	221.98	180	10.15	1.83	8.06	1.34	41 8	23 5	13.1	32 290	62 270	"	40 409	.9746	.5574	42 8	21.3	40 630	72 240	056	" " "	" " "	" " "
Second part	"	10	1⅛	221 98	180	10 13	1.81	....	....	....	14.1	6.2	31 910	58 050	Head	40 409										
Retest of above. Reheaded, not reannealed	"	10	1⅛	172.43	120	10.13	1 81	8 43	1 38	36.6	15.7	13 1	.....	65 170	Body	40 409										
High steel bar cut in two. Reheaded, not reannealed. Test completed as below	East intermediate	10	1	361.68	312	10.04	0 99	8 22	0.71	41.2	17.1	16 1	29 970	58 080	"	40 414	1.0220	.6371	45 7	27.0	40 610	70 480	050	" " "	" " "	" " "
	"	7	1¼	258.68	228	7.01	1.27	5 31	0 99	46.3	38.2	16.8	29 640	56 830	"	11 072	1.0200	5402	47.0	28 1	40 700	68 730	030	" " "	" " "	" " "
First half above. Broke in unannealed end near heat line of new head	"	8	1⅛	478.88	432	8.03	1.75	....	....	....	62 7	12.2	32 220	61 260	Not broken	10 770	1.0020	6013	40 0	28.1	40 920	76 150	042	" " "	" " "	" " "
Second half broke like above. Area between fracture and new head reduced 24.3 per cent.	"	8	1⅛	236.28	168	8.03	1.75	6.22	1 18	47 8	22.1	13.2	.....	54 720	Body	10 770										
	"	8	1⅛	240.28	180	8.03	1.75	7.44	1.60	15.3	20.1	11.2	.....	57 130	"	10 770										
Bar cut in two. Reheaded, not reannealed. Retested as below	"	8	1⅛	478 88	432	8.00	1.26	....	....	....	51 7	12.0	32 280	62 950	Not broken	10 770										
First part of above	"	8	1⅛	236.09	156	8 00	1.26	6 29	0 94	41.37	25 8	16.5	.....	68 590	Body	10 770										
Second part of above. Broke in unannealed part of bar on heat line of new head	"	8	1⅛	238 18	168	8.00	1.26	6 41	0 86	45.0	18 2	10 8	.....	58 880	"	10 770										
	"	8	1⅛	354.63	216	7.98	1.29	6.14	0 92	41 0	33.2	15 4	31 930	63 870	"	10 828	1.0100	4108	59.3	21 9	40 900	69 800	024	" " "	" " "	" " "
Soft steel suspenders	West intermediate	7	1⅛	338.58	300	8 03	2.42	6 74	1 77	29 8	34.6	11.5	32 840	62 480	"	10 680	1.0020	.6943	44 0	23 1	41 710	71 000	.056	" " "	" " "	" " "
" " Full capacity of machine reached	"	7	1⅛	258.68	216	7.99	1.18	5.27	0 86	45.8	36.8	17.0	27 870	53 520	"	20 816	1.0560	4995	52.7	31.9	32 480	58 050	027	" " "	Penceyd B & C Co.	
" " First part	"	9	2⅛	338.58	300	9.00	2 31	....	....	10 5	35.3	11.8	27 730	54 400	Not broken	09 257	1.0900	.5416	50 3	29 5	39 900	66 780	.013	" " "	Keystone Bridge Co.	
" " Second part	"	9	1⅛	206.58	168	9.09	1.25	6 81	0 83	50.3	39 1	23.3	32 590	57 410	Body	09 405	.9734	4488	53.8	28 7	38 110	66 920	.014	" " "	" " "	" " "
Lower lateral. Broke at back end of upset for screw, disclosing piece of iron welded in	"	6	1⅛	409.08	348	6.07	1 18	....	....	....	19.5	5 6	35 480	60 300	"	09 405										
Lower lateral	"	6	1⅛	416.78	360	6.04	1.18	....	....	....	21.6	6 0	39 190	63 220	In upset for screw	3 055	830	435	47 6	23.0	39 760	74 340	069	Acid	Penceyd L & S. Co.	Penceyd B & C Co.
" "	"	4	1⅛	422.18	372	4 03	0.80	3.25	0.57	42.6	30.2	10.6	40 540	71 580	Sleeve nut	3 327	.672	.303	54 9	27.5	41 670	71 740	082	" " "	" " "	" " "
" "	"	4	1⅛	421.88	372	4 02	1.09	3.10	0.75	41 8	45.1	12.1	39 670	68 490	Body	3 095	1.026	436	68.5	31 3	39 280	66 090	084	" " "	" " "	" " "
" "	"	4	1⅛	423.08	372	4.04	1.13	3 08	0.79	46 8	47.8	12 8	39 720	69 180	"	3 095	.....	.....	.....	.....	.....	.....	.....	" " "	" " "	" " "
First part	Deck span	8	1⅛	279.98	240	8.11	1.79	6.26	1.34	42.2	37.1	16.5	28 940	58 010	"	11 160	1.114	.5060	46.5	23.0	40 480	66 880	.030	Basic	Carnegie, Phipps & Co.	Union Bridge Co.
Second "		8	1⅛	279.88	240	8.11	1 79	6.13	1.24	47.7	38.8	16.2	28 660	58 200	"	11 150										
First "		7	1	229.23	252	7.02	1 00	5.53	0.75	60.9	44 9	17.8	31 380	59 850	"	11 072	1 020	5402	47 0	28.1	40 790	68 730	.030	" " "	" " "	" " "
Second "		7	1	249.48	252	7.00	1.00	5.51	0.67	47.3	42.7	16 9	31 470	59 730	"	11 072										

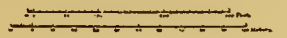
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE I.

K.C.&M.R.&B.Co.

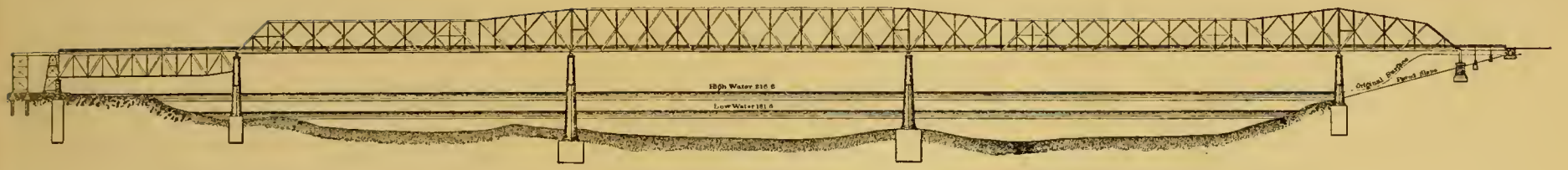
MEMPHIS BRIDGE.

GENERAL ELEVATION AND PLAN.

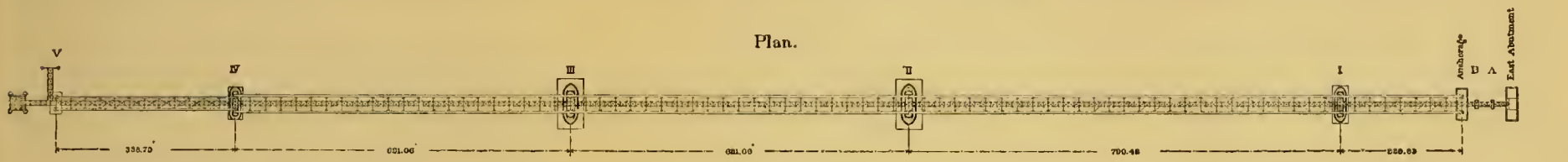
Scale.



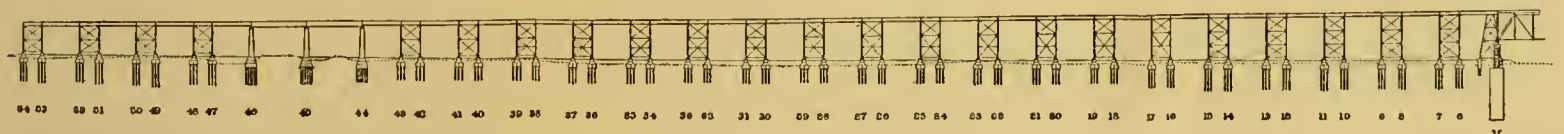
Elevation.



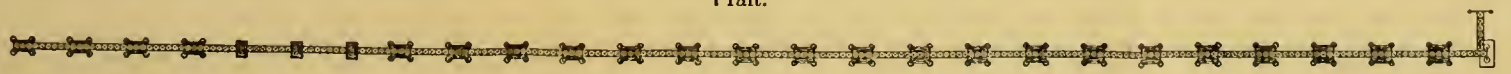
Plan.



Elevation.



Plan.

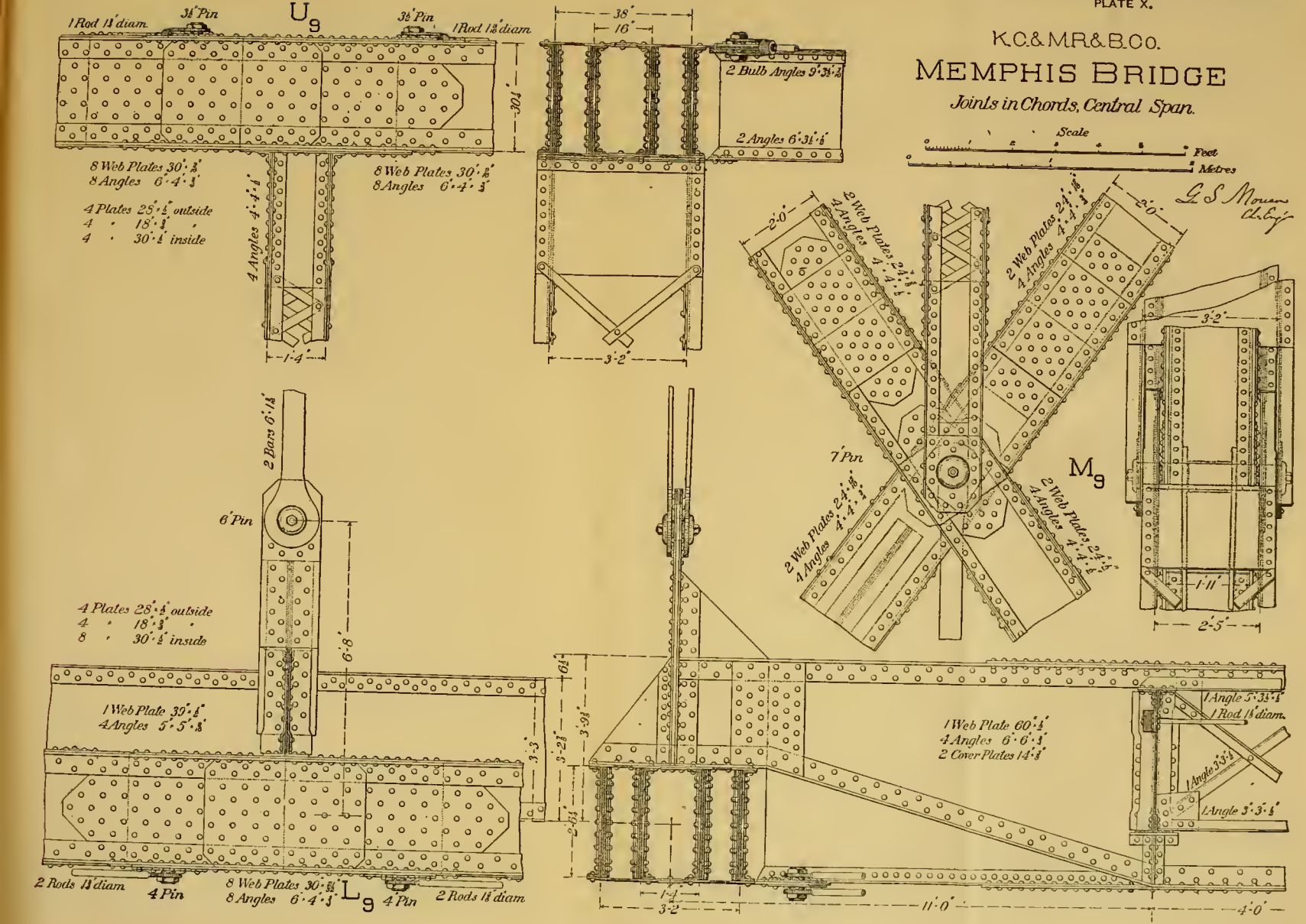


VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE X.

K.C.& M.R.& B.Co.

MEMPHIS BRIDGE

Joints in Chords, Central Span.

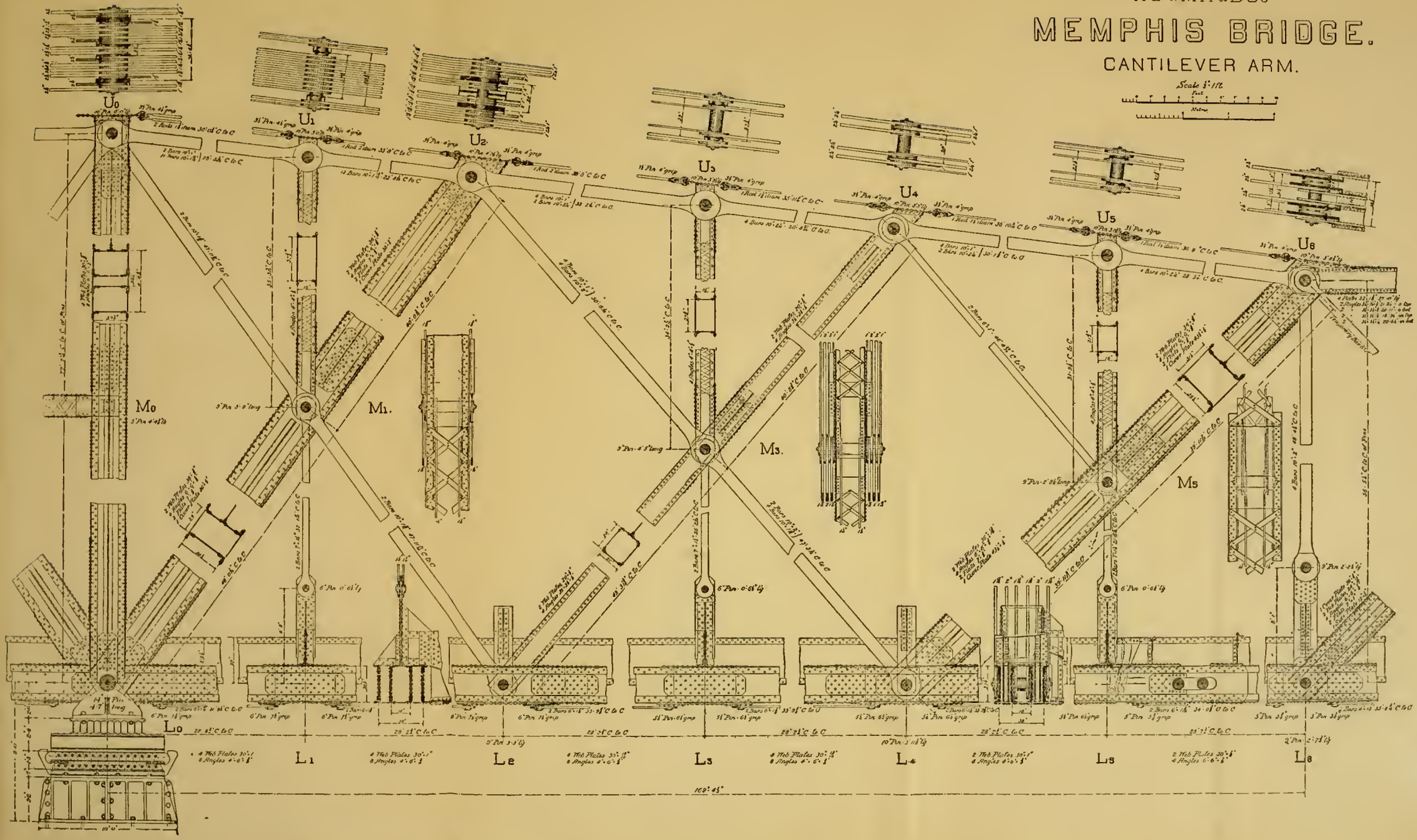


VOL. XXIX, No 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE III.

KC & MR & BCo.

MEMPHIS BRIDGE.

CANTILEVER ARM.

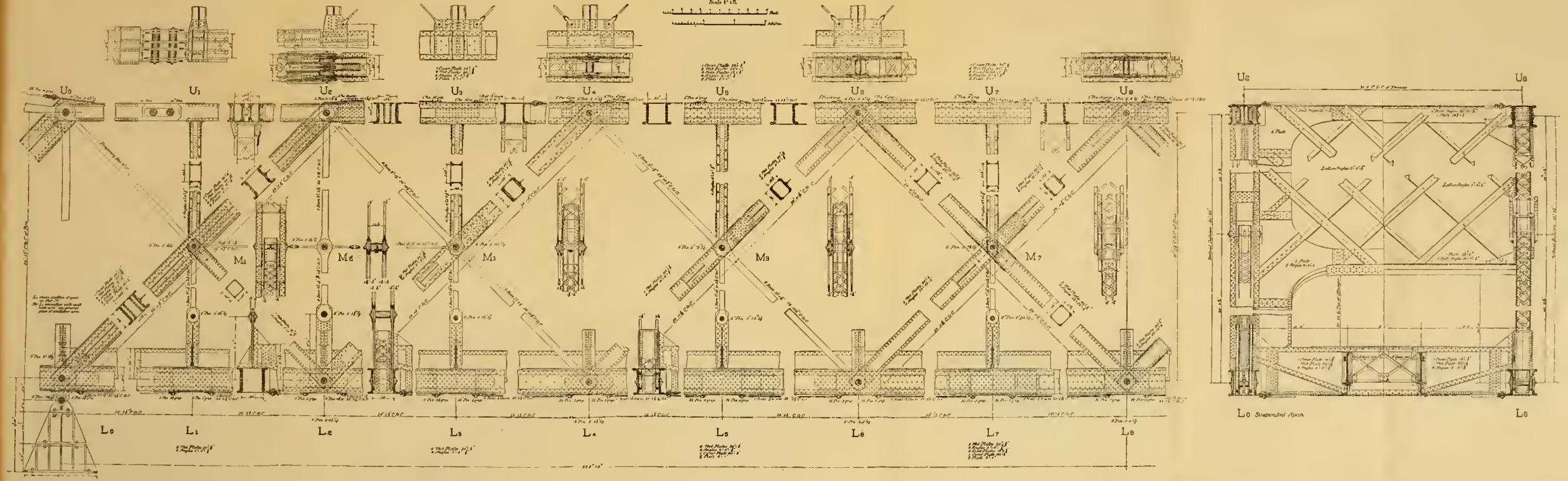


VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE
PLATE IV.

K.C.&M.R.&B.Co

MEMPHIS BRIDGE.

INTERMEDIATE SPAN

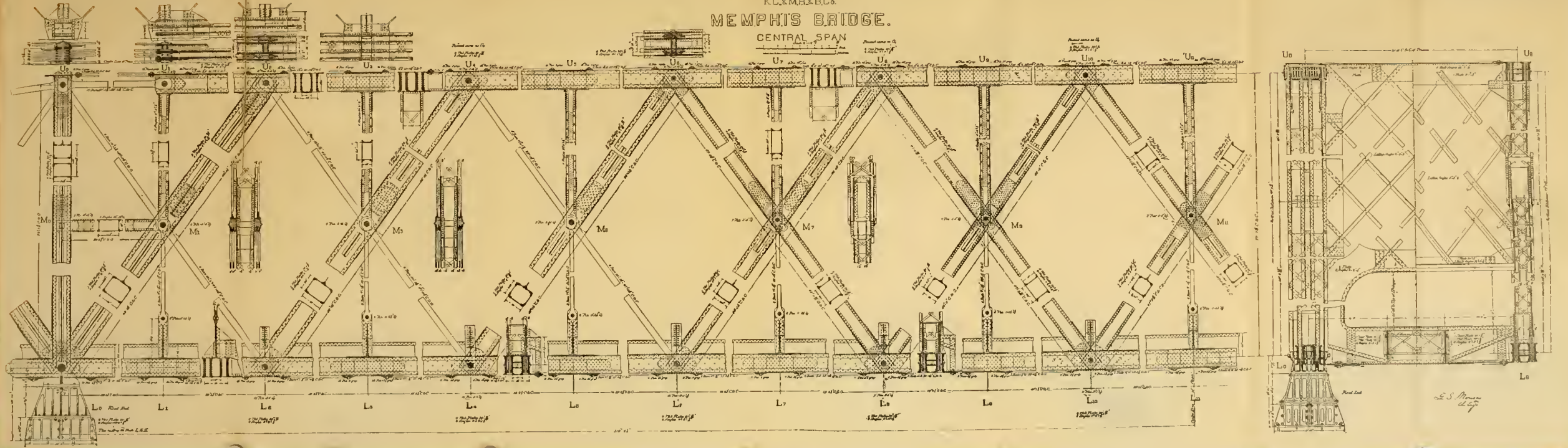


VOL. XXIX, No. 624
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE V.

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE.

CENTRAL SPAN

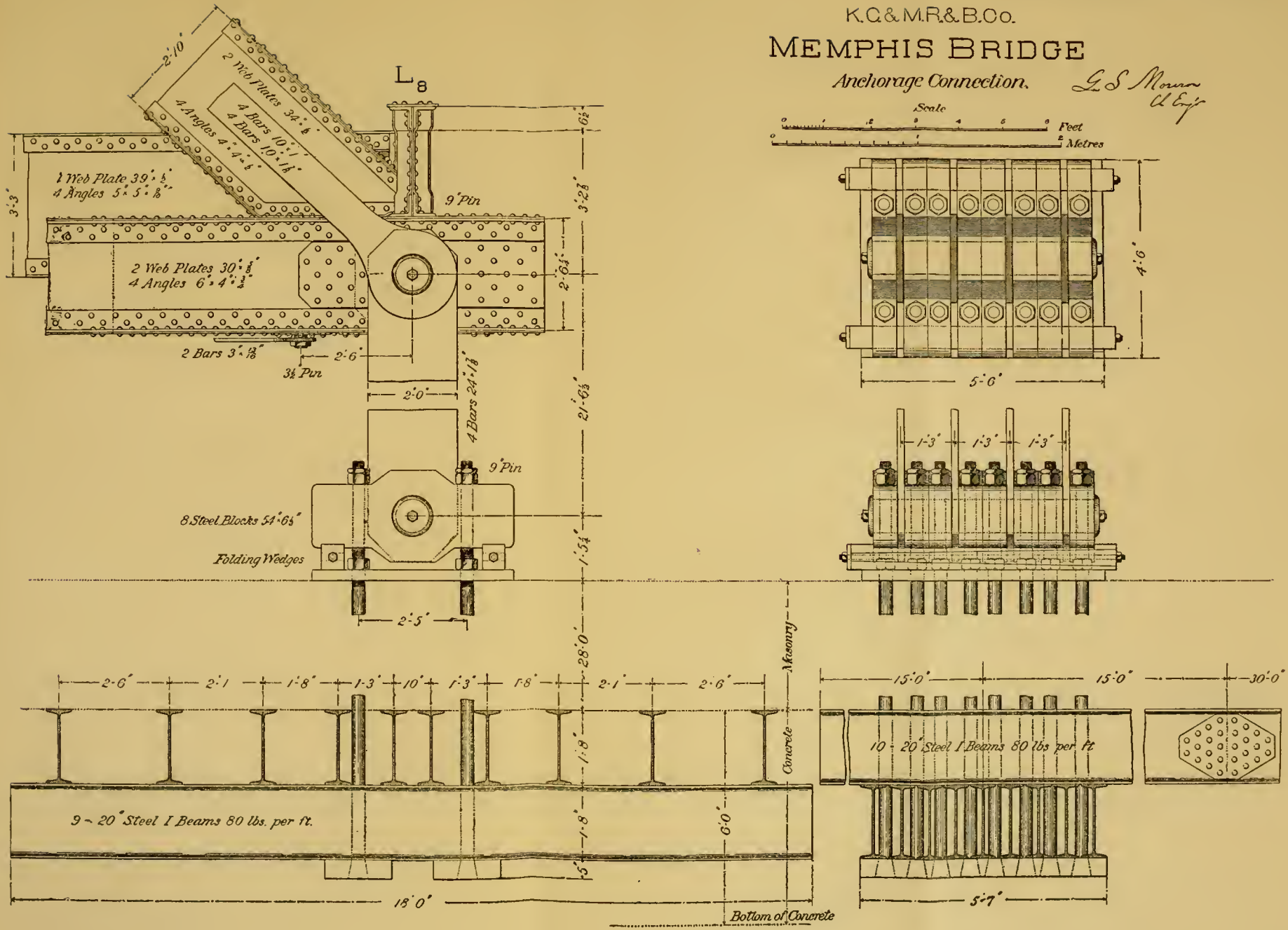


K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

Anchorage Connection.

G. S. Morison
M. Engr.

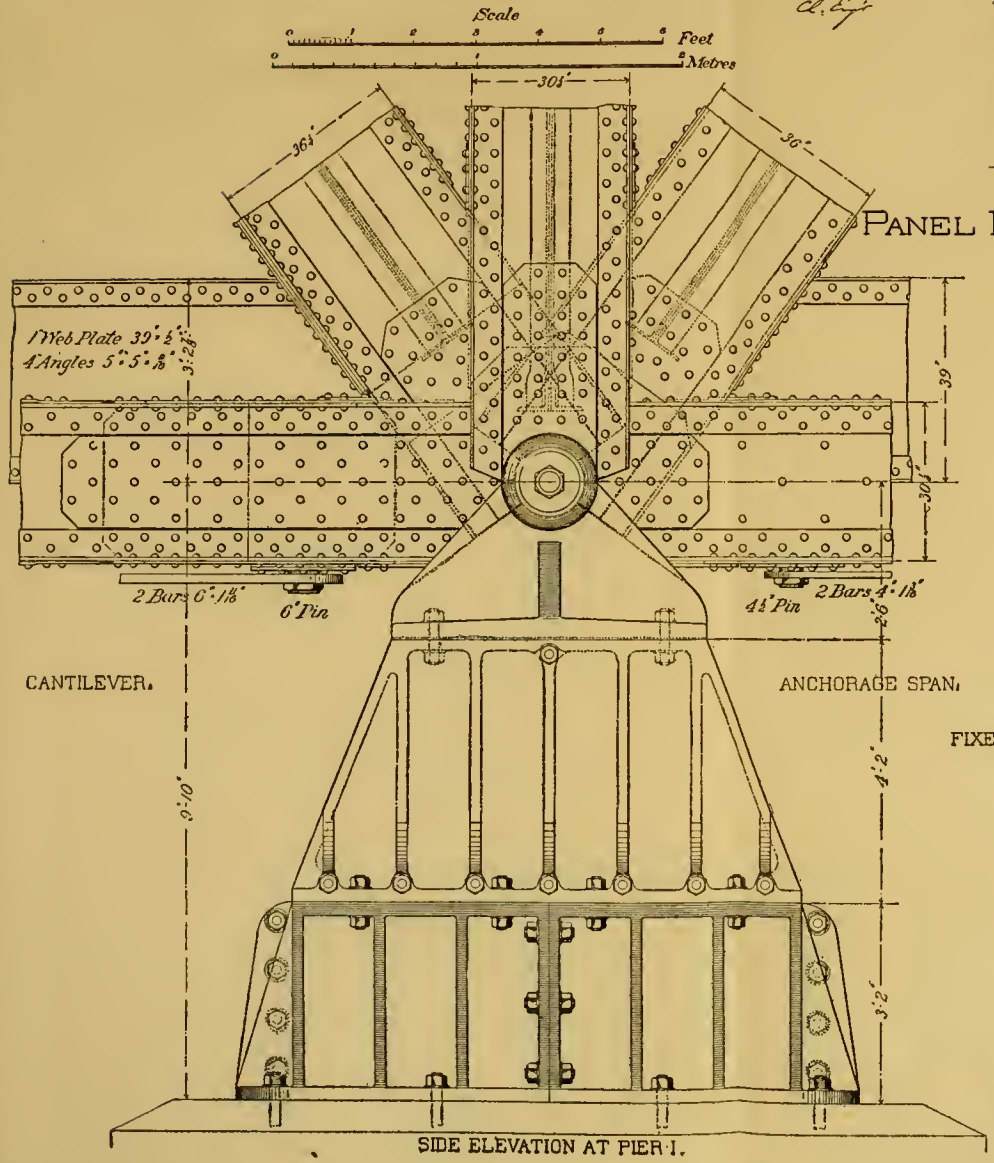


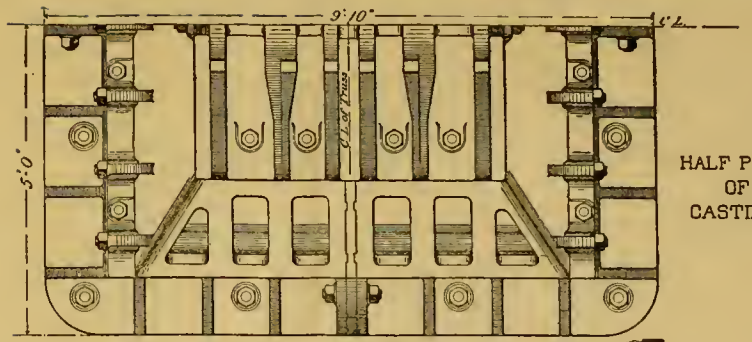
K.C.&M.R.&B.Co.

MEMPHIS BRIDGE.

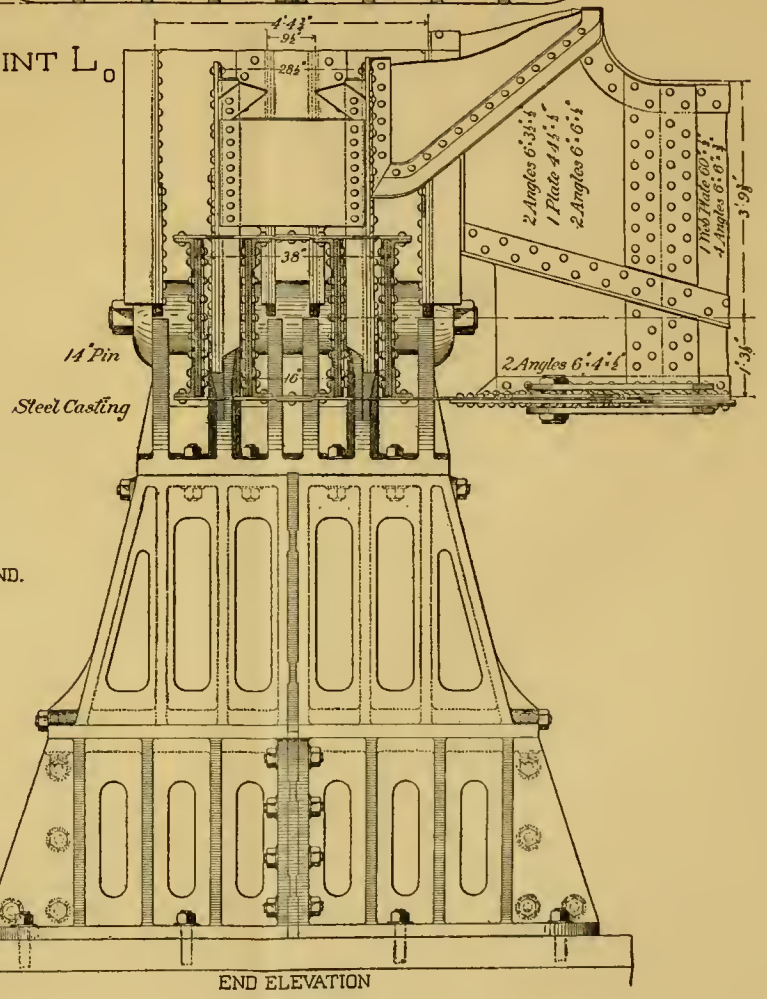
Bearings, Piers I and III

G. S. Morison
Ch. Eng.

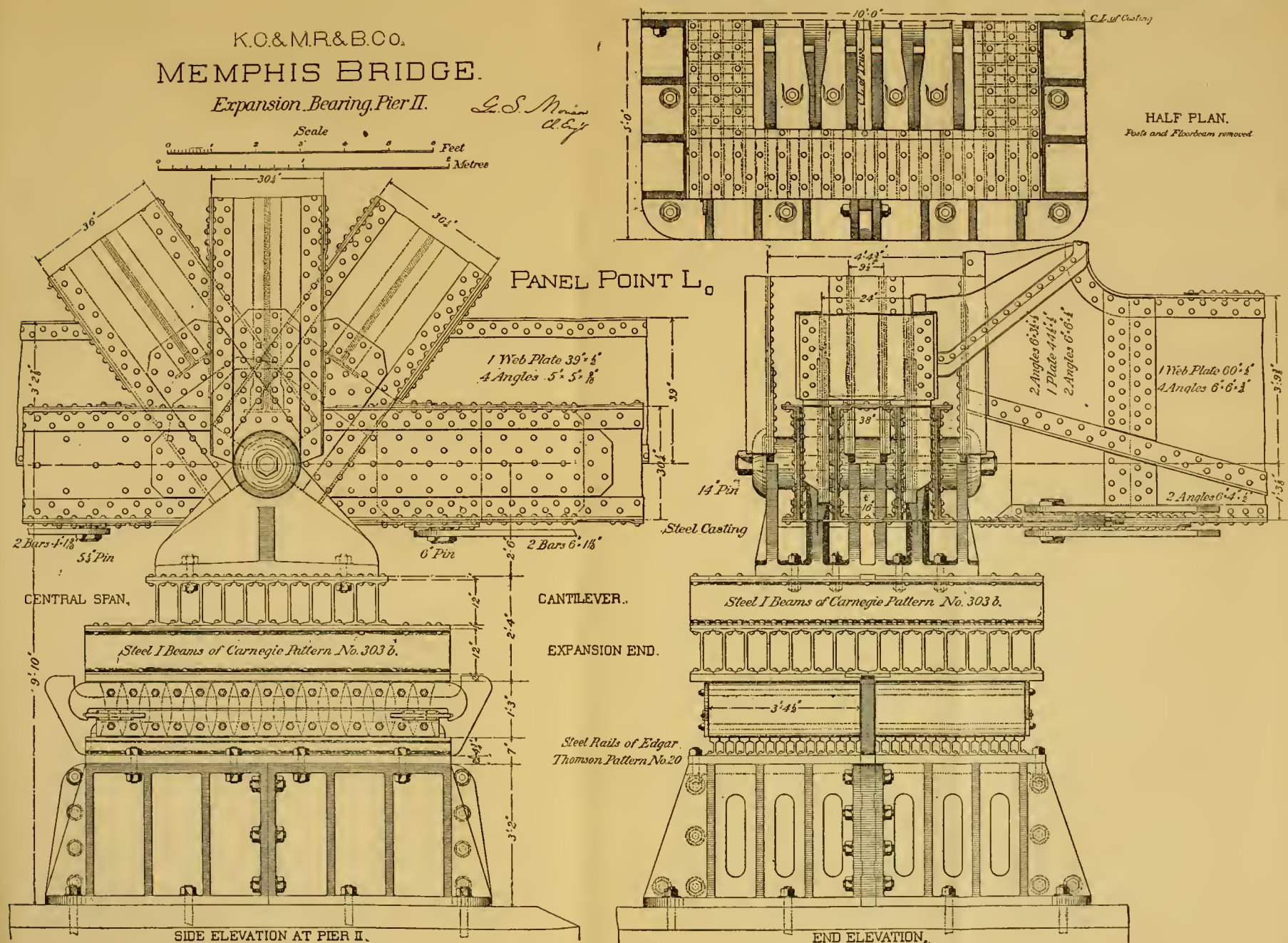


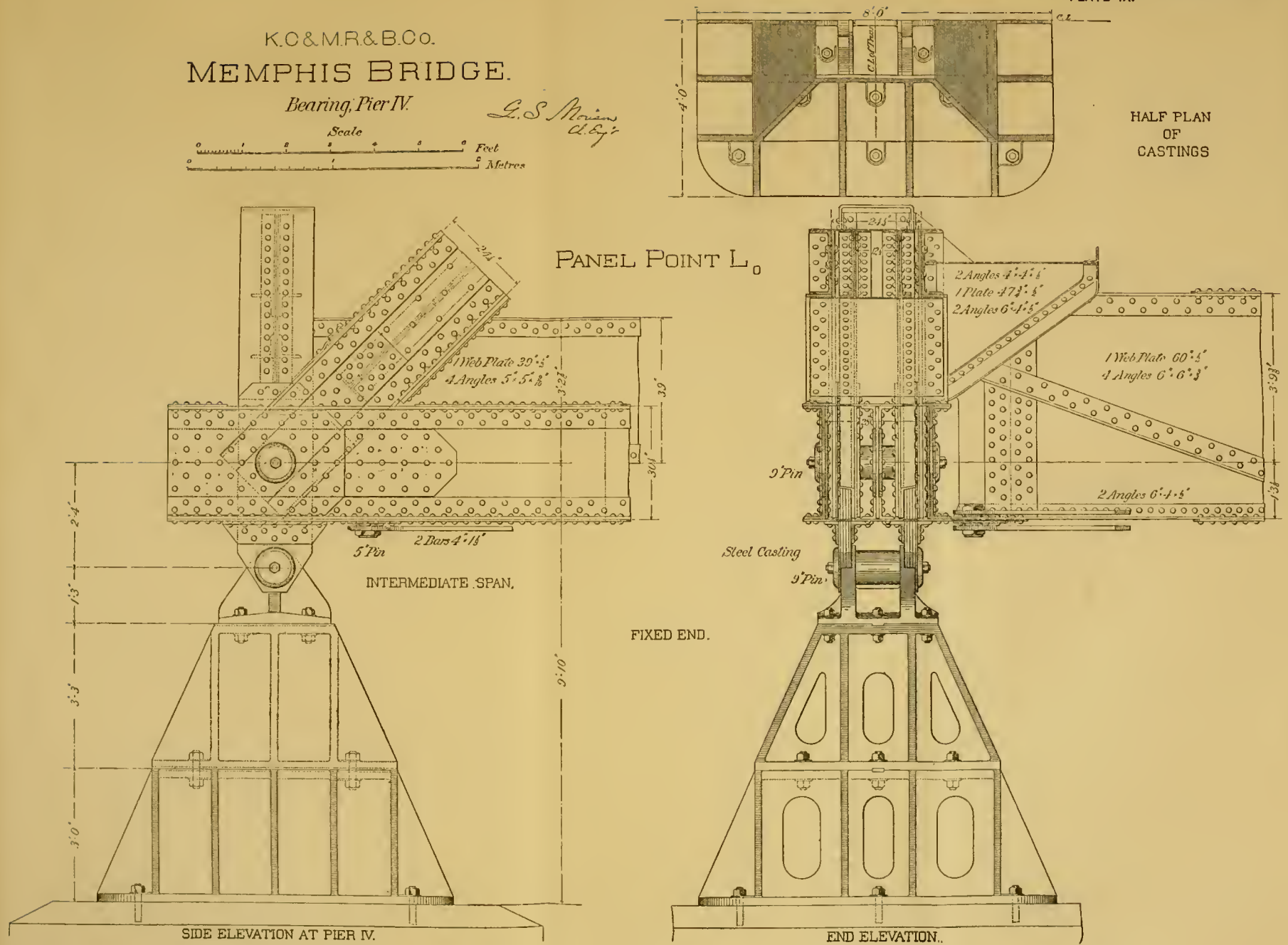


PANEL POINT L_0



VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE VIII.



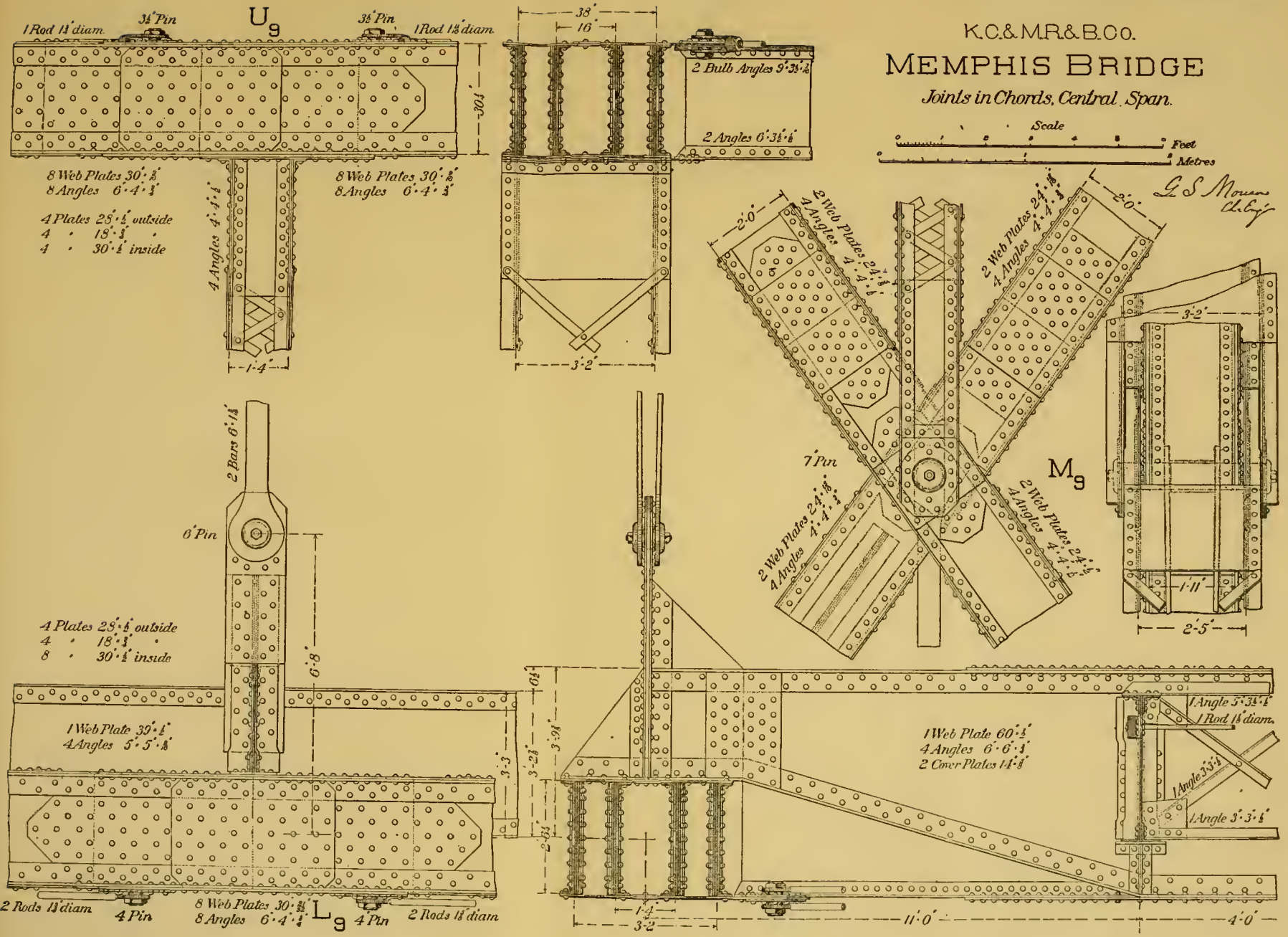

K.C.&M.R.&B.Co.
MEMPHIS BRIDGE.
Bearing, Pier IV.
Scale
Feet
Metres
G. S. Morison
Ch. Eng'r
HALF PLAN
OF
CASTINGS
8'-0"
4'-0"
PANEL POINT L0
1 Web Plate 39"×½"
4 Angles 5"×5"×⅜"
2 Bars 4"×1½"
5" Pin
INTERMEDIATE SPAN.
2'-4"
1'-3"
3'-3"
3'-0"
9'-10"
2 Angles 4"×4"×½"
1 Plate 47¾"×½"
2 Angles 6"×4"×½"
1 Web Plate 60"×½"
4 Angles 6"×6"×⅜"
2 Angles 6"×4"×½"
9" Pin
Steel Casting
9" Pin
FIXED END.
SIDE ELEVATION AT PIER IV.
END ELEVATION.

VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE X.

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

Joints in Chords, Central Span.



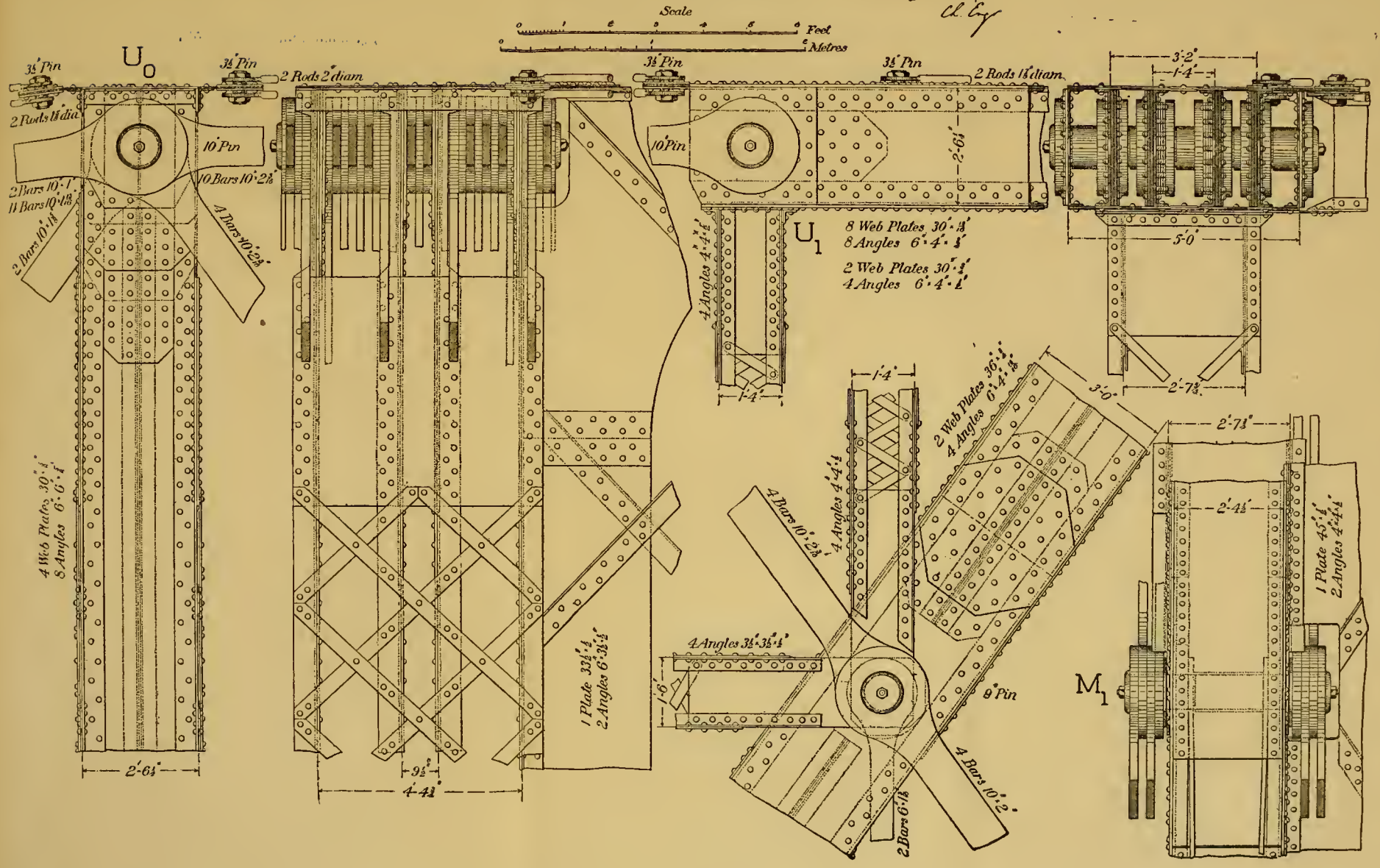
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XI.

K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

U_0 Panel Point, Central Span.

G. S. Morison
Ch. Eng.



VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XII.

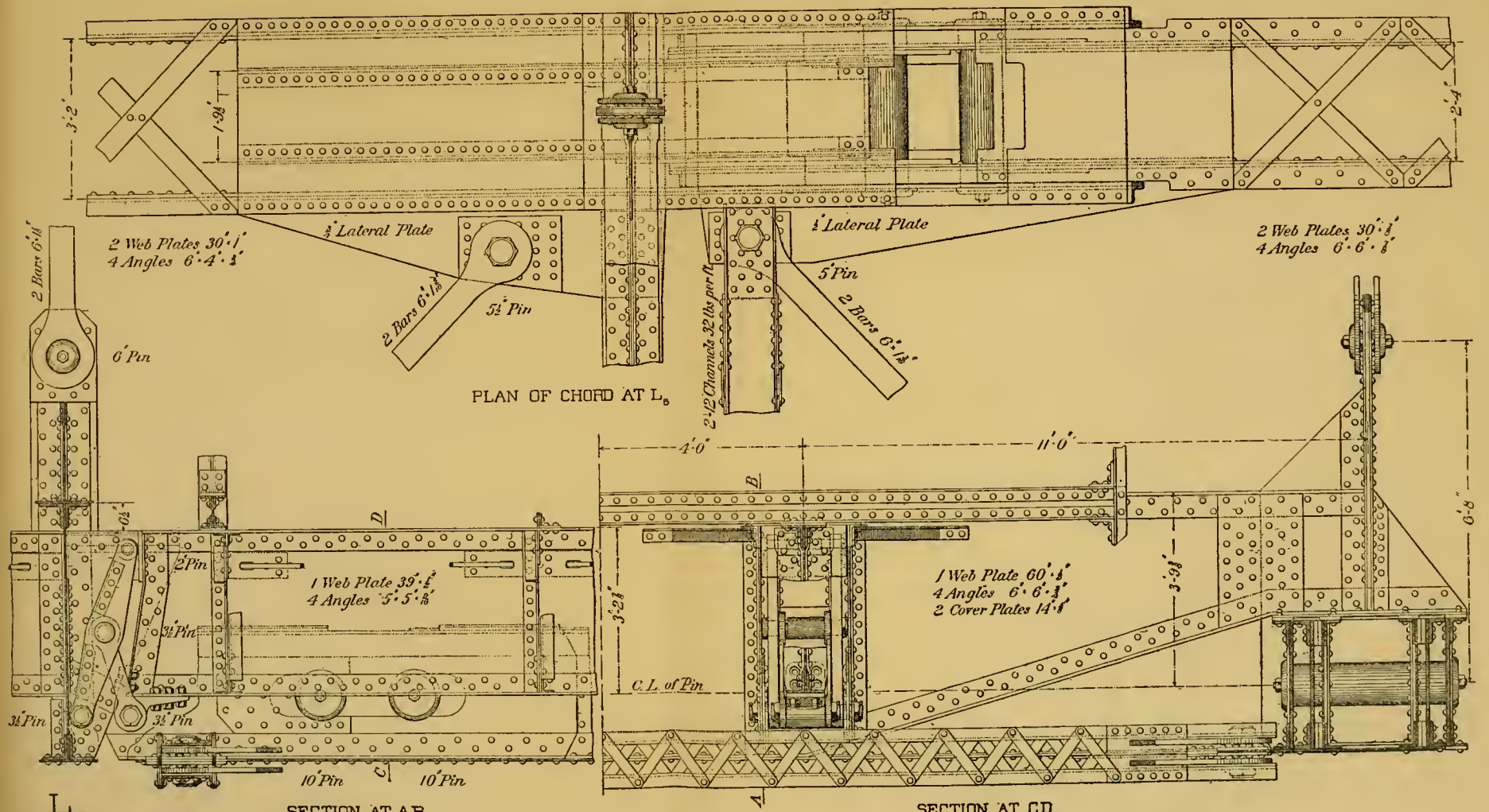
K.C.& M.R.& B.Co.

MEMPHIS BRIDGE

Expansion Joints: Lower Chord and Stringers, Intermediate Span.

Scale
0 Feet
0 Metres

G. S. Morison
Ch. Eng.



VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XIII.

K.C.& M.R.& B.Co.

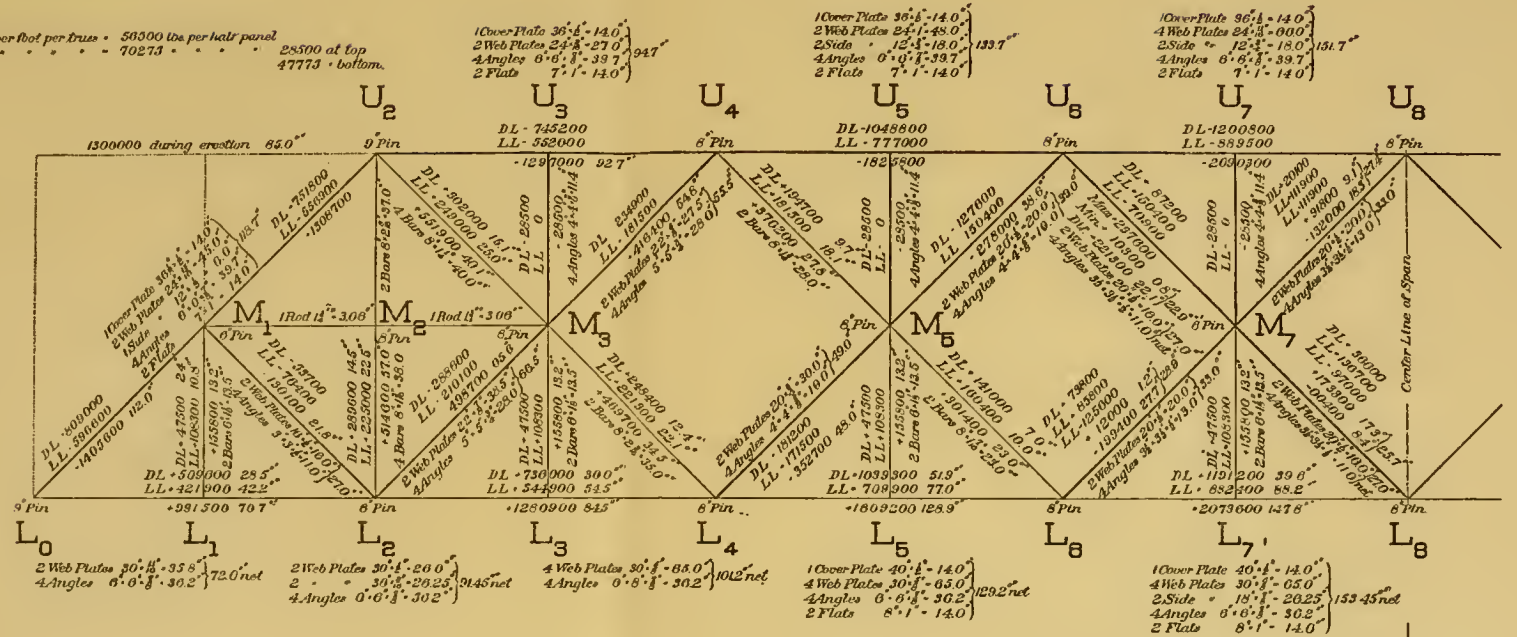
MEMPHIS BRIDGE

Strain Sheet, Intermediate Span.

G. S. Morison
M. Engr

Intermediate Span 481'-8" C. to C. End Pins;
equal sixteen (16) half panels of 28'-2½" each;
30'-0" C. to C. Trusses; 58'-5½" C to C Chords

Live Load 2000 lbs per foot per truss = 56300 lbs per half panel
" " 2700 " " " " " = 70273 " " " " 28500 at top
47773 " bottom.



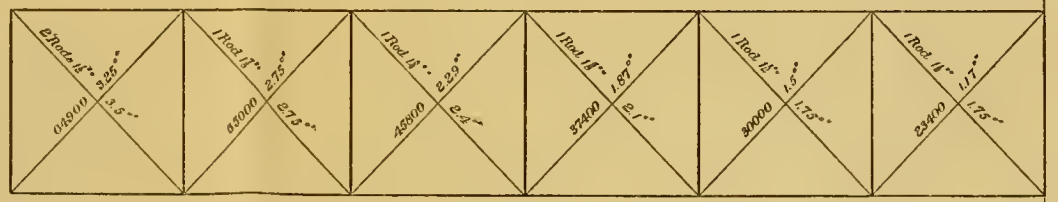
2 Web Plates 30"x⅜" - 33.8"
4 Angles 6"x6"x⅜" - 30.2" } 72.0" net

2 Web Plates 30"x⅜" - 26.0"
2 " 30"x⅝" - 26.25" } 91.45" net
4 Angles 6"x6"x⅜" - 30.2"

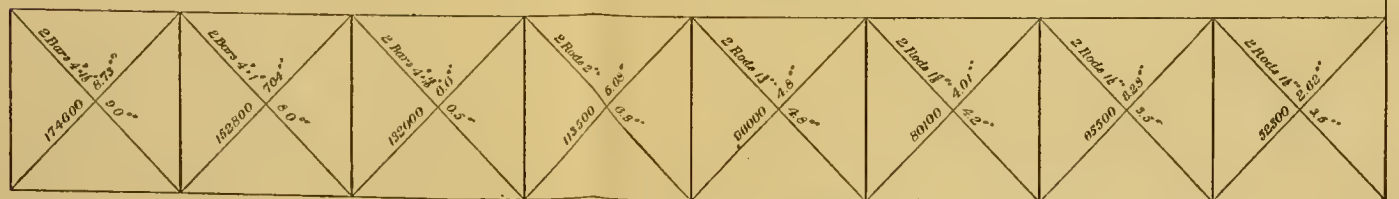
4 Web Plates 30"x⅝" - 65.0"
4 Angles 6"x6"x⅜" - 30.2" } 101.2" net

1 Cover Plate 40"x⅝" - 14.0"
4 Web Plates 30"x⅝" - 65.0"
4 Angles 6"x6"x⅜" - 30.2" } 129.2" net
2 Flats 8"x1" - 14.0"

1 Cover Plate 40"x⅝" - 14.0"
4 Web Plates 30"x⅝" - 65.0"
2 Side " 18"x½" - 26.25" } 153.45" net
4 Angles 6"x6"x⅜" - 30.2"
2 Flats 8"x1" - 14.0"



TOP LATERAL SYSTEM.



BOTTOM LATERAL SYSTEM.

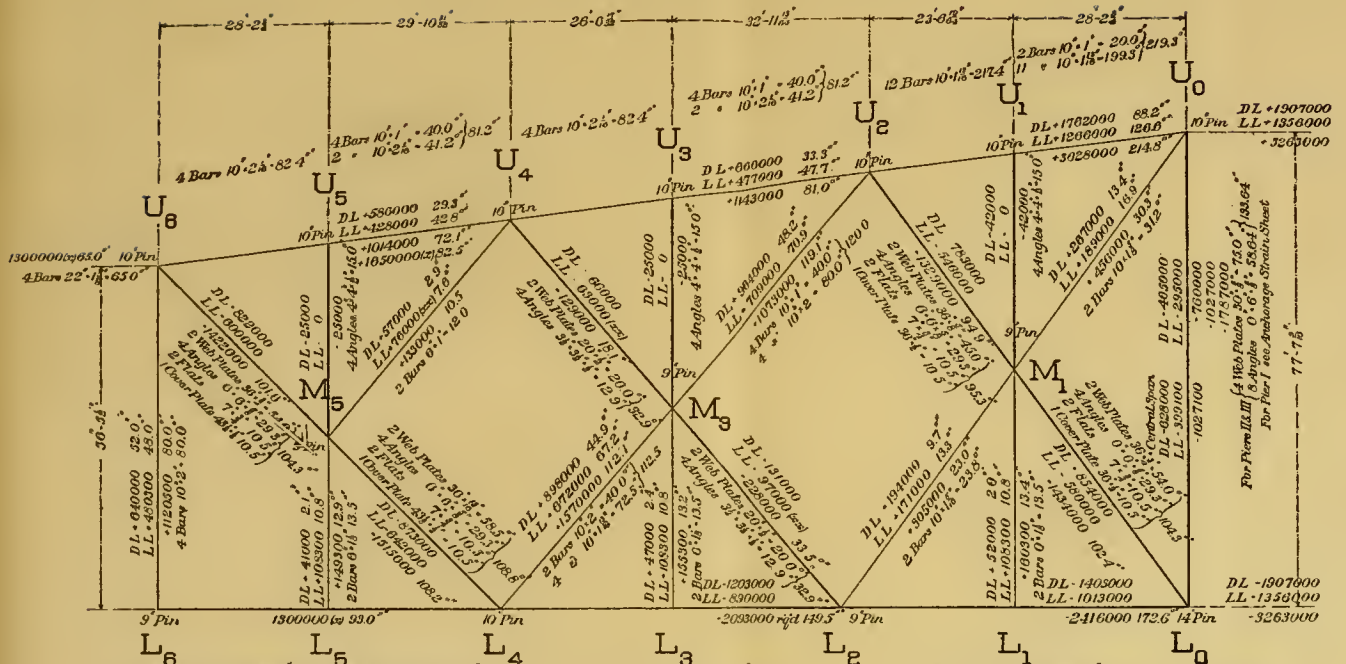
Assumed Wind Pressure,
300 lbs. per foot at top
600 " " " bottom

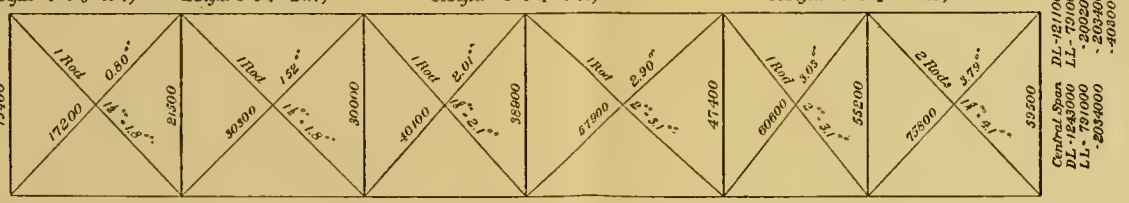
K.O.& M.R.& B.Co.

MEMPHIS BRIDGE

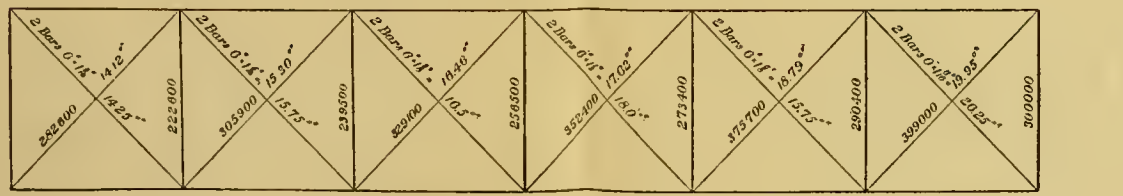
Strain Sheet, Cantilever Arm.

E. S. Morison
M. Engr.





TOP LATERAL SYSTEM.



BOTTOM LATERAL SYSTEM.

Cantilever Arm 162'-4½" C. to C. End Pins; equal sts 161 half panels of 28'-2½" at Bottom Chord; 30'-0" C. to C. of Trusses.

Actual Dead Load taken in Strain Sheet.					
L_0	52000			U_0	31000
L_1	52000	M_1	25000	U_1	42000
L_2	56000			U_2	40000
L_3	47000	M_3	27000	U_3	25000
L_4	04000			U_4	17000
L_5	41000	M_5	12000	U_5	25000
L_6	15000			U_6	15000
	023000				

(x) Occurs only during erection.
(xx) Assuming LL of 108800 applied at L_5

Live Load per Truss
2000 lbs per foot = 56500 lbs per one half panel.

Assumed Wind Pressure - 300 lbs. per foot at top
" " " 600 " " " bottom.

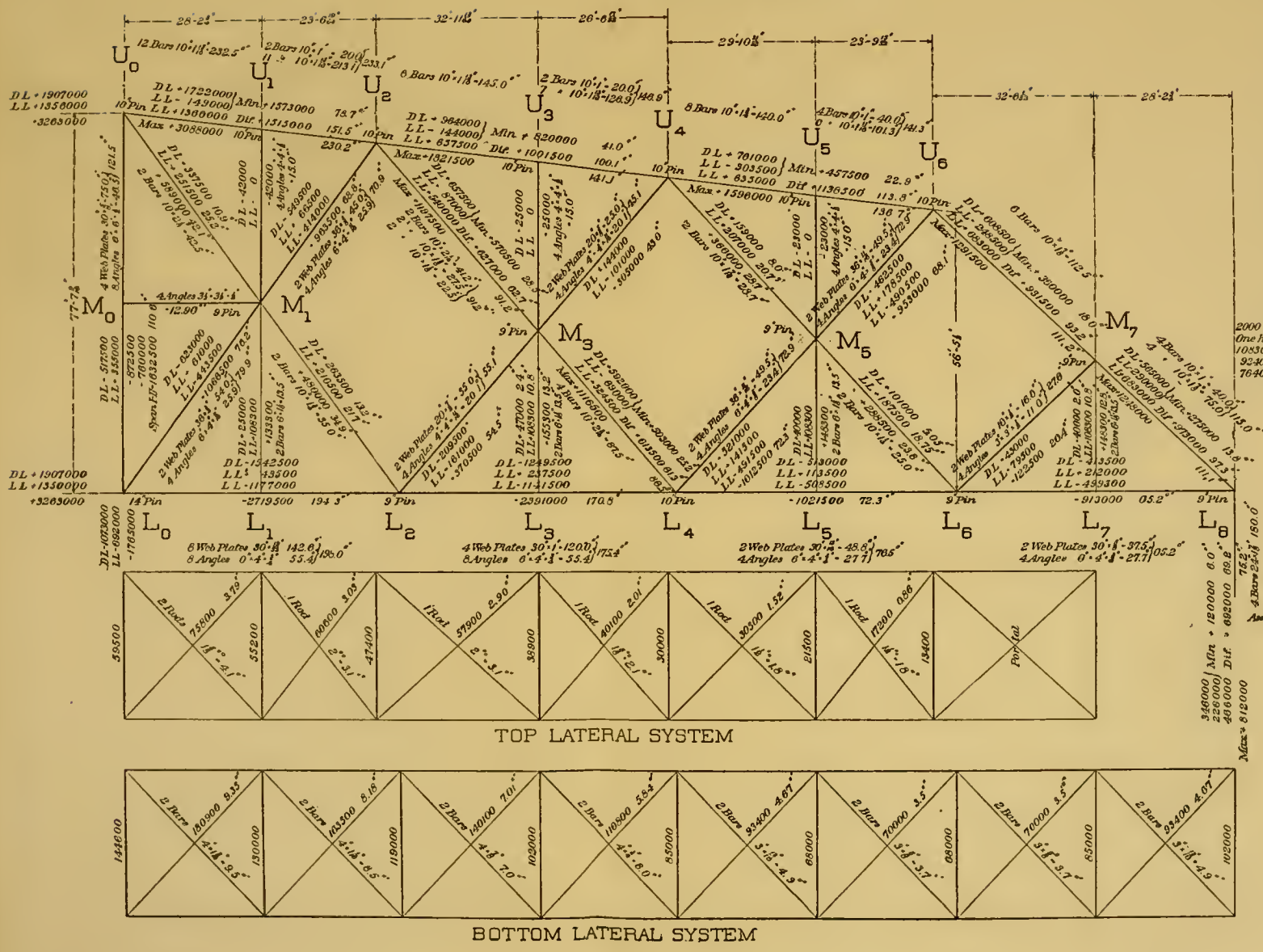
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XV.

K.C.& M.R.& B.Co.

MEMPHIS BRIDGE

Strain Sheet, Anchorage Arm.

G. S. Morison
Ch. Eng'r



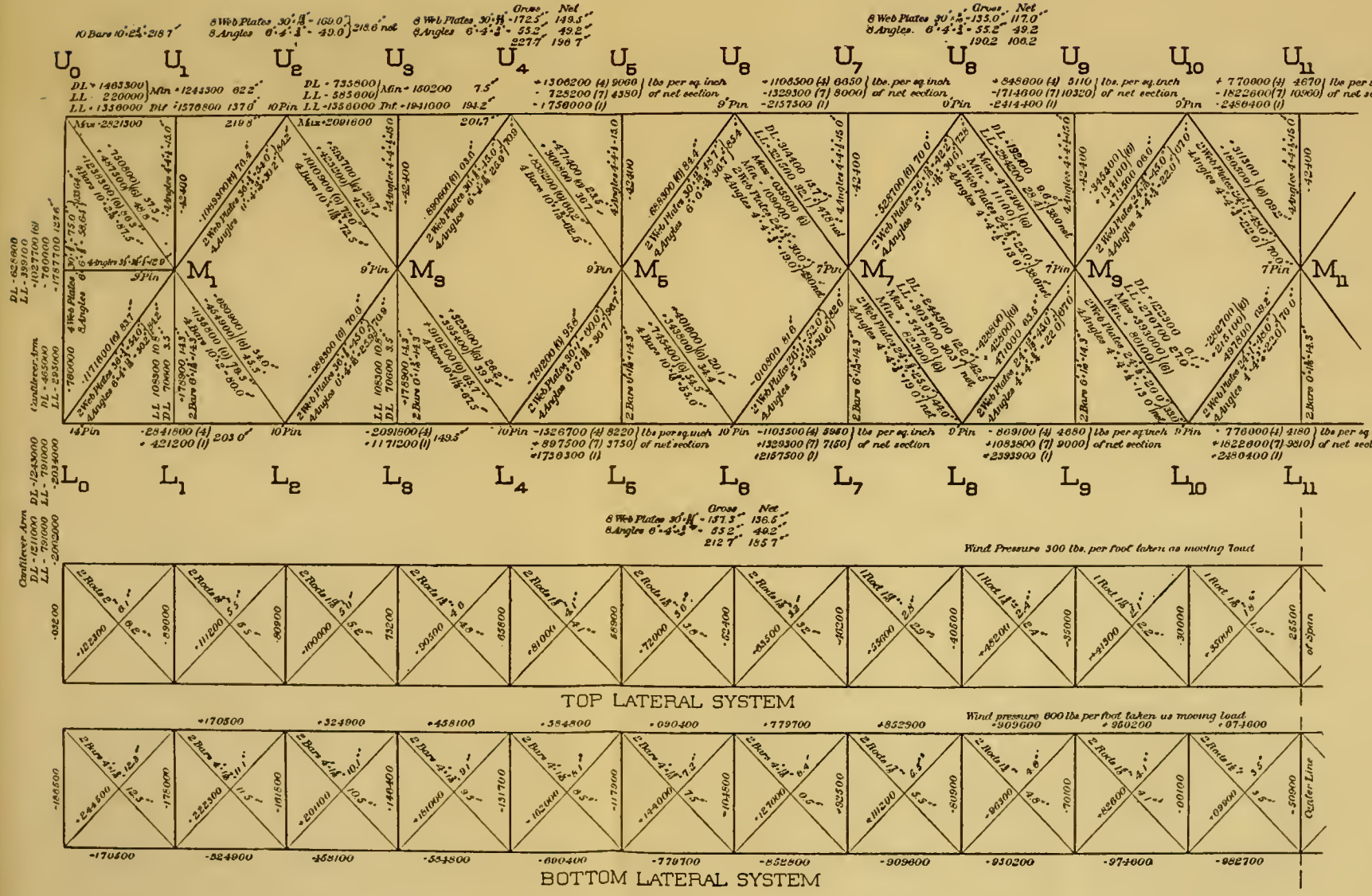
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XVI.

K.C.& M.R & B.Co

MEMPHIS BRIDGE

Strain Sheet, Central Span

G S Morison
Ch Engr



K.C.&M.R.&B.Co.

MEMPHIS BRIDGE

Strain Sheet Details, Central Span.

G. S. Morison
Ch. Engr.

Central Span. 621·0½ C. to C. End Pins, equal twenty two (22) half panels of 28·2¾' each
30'·0" C. to C. Trusses. 77'·7⅞" C. to C. Chords

DL = 4000 lbs per foot per truss + 113000 lbs per ℄ panel { 42400 lbs at top / 70600 " " bottom
LL = 2000 " " " " " = 56500 " " ℄ "
EL = 3000 " " " " " = 84750 " " ℄ "

Independent Span DL only

2nd. Central Span DL - both side spans DL

3rd. Central Span DL - one side DL other DL and LL

4th. Central Span DL - both side spans DL and LL

Max tension top chord
" compression bottom "

Web members same as in 1st supposition

5th. Central Span DL and LL both side spans DL and LL

6th. Central Span DL and LL - one side DL and LL other DL

Maximum web strains

7th. Central Span DL and LL both side spans DL

Max compression top chord
" tension bottom "

Web members same as in 5th supposition

Resultant maxima and minima strains

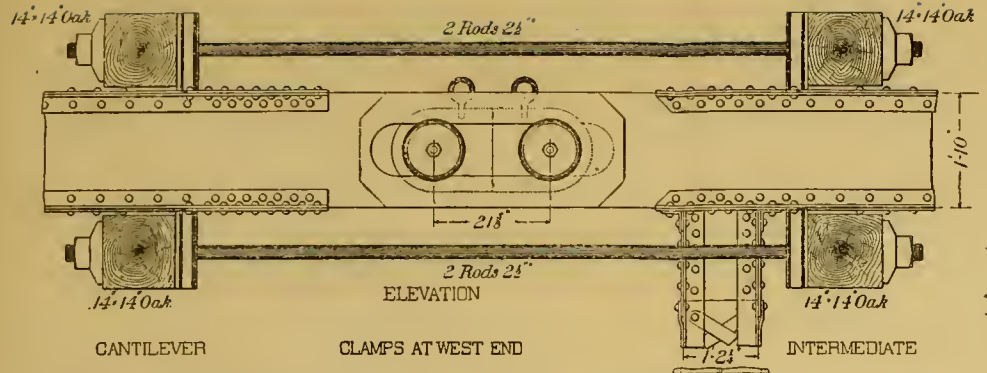
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XVIII.

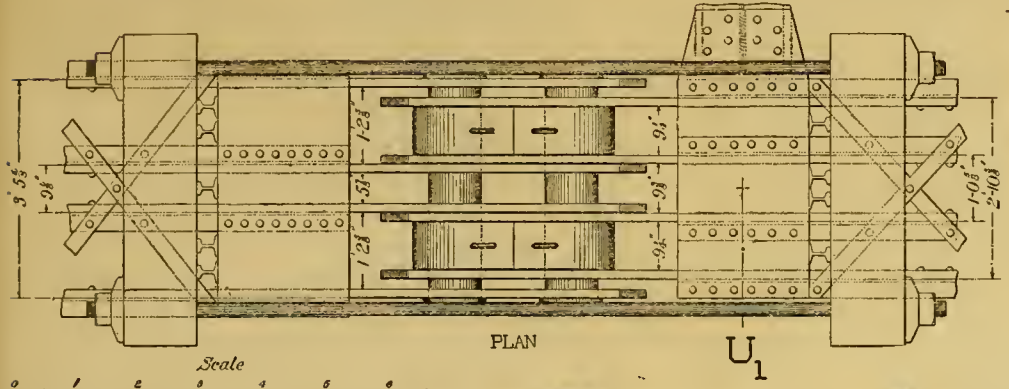
K.C.&M.R.&B.Co.

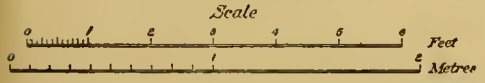
MEMPHIS BRIDGE

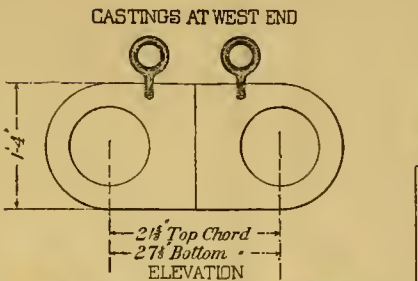
Adjustments at Ends. Intermediate Span.

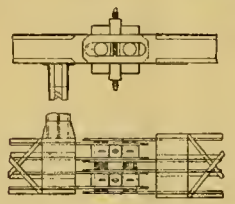
G. S. Morison
M. Engr

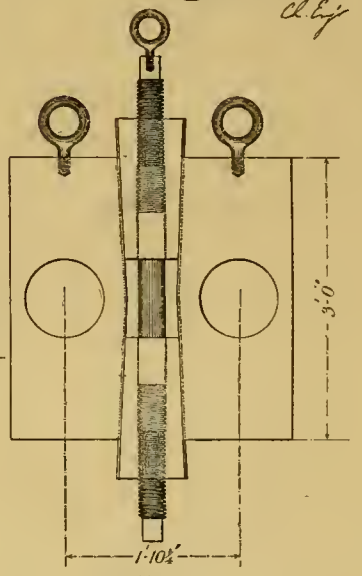


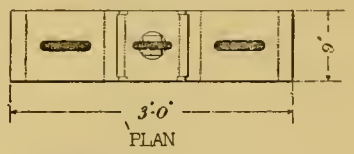




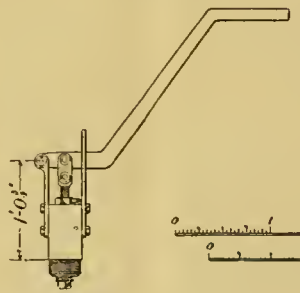




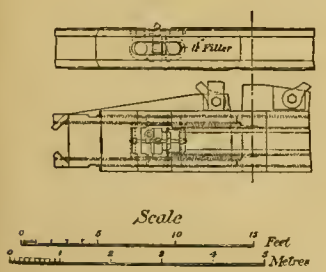


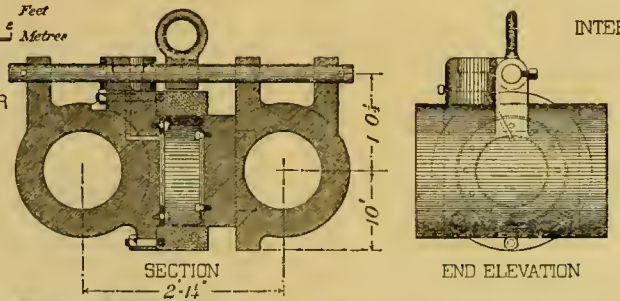


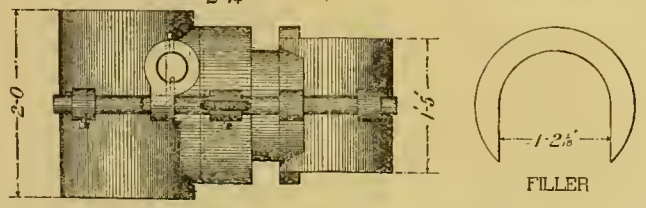
WEDGES AT EAST END



PUMP FOR HYDRAULIC ADJUSTMENT







HYDRAULIC ADJUSTMENT AT EAST END

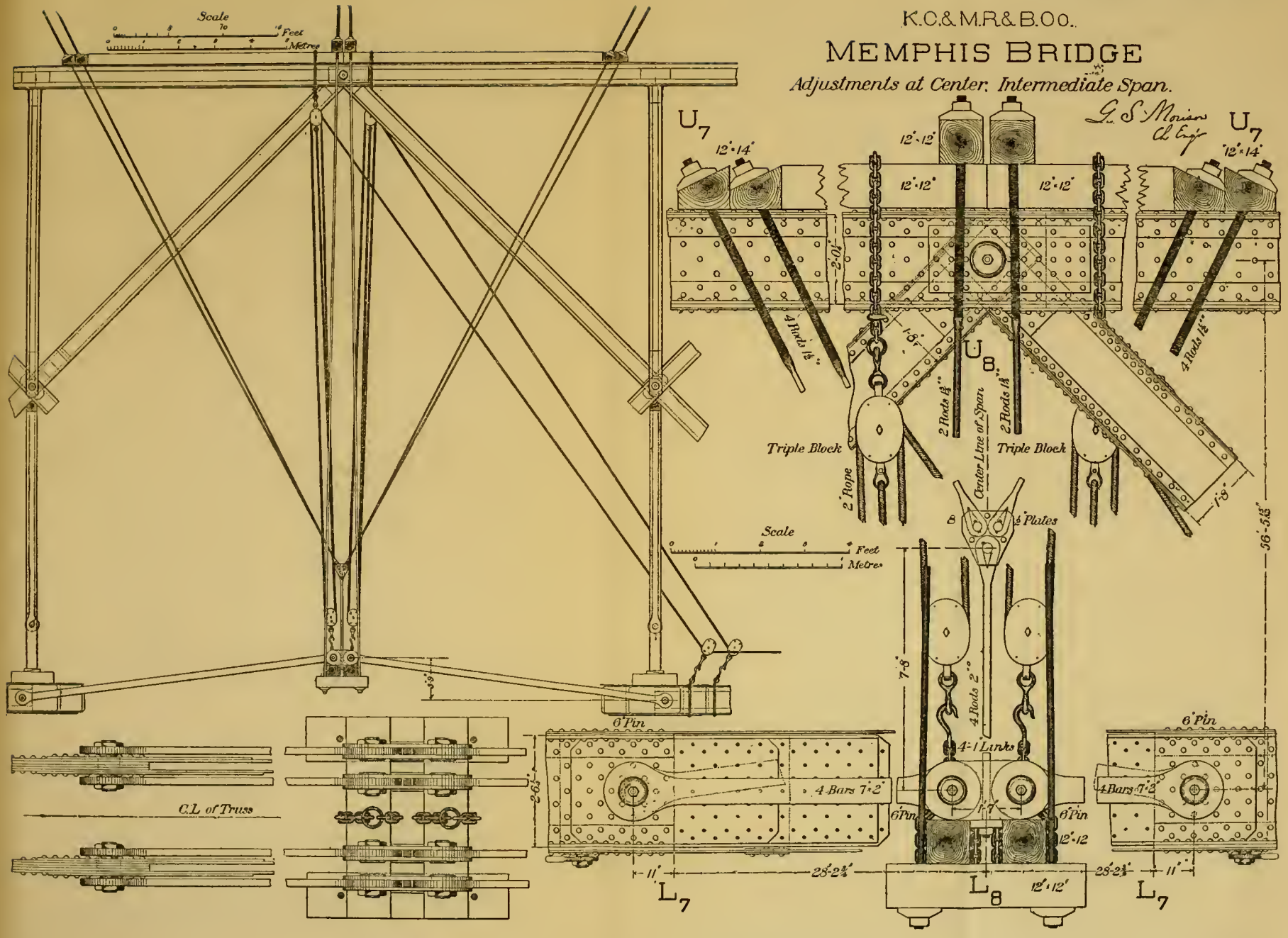
VOL. XXIX, No. 624.
TRANS. AM. SOC. CIV. ENGRS.
MORISON ON SUPERSTRUCTURE OF MEMPHIS BRIDGE.
PLATE XIX.

K.C.& M.R.& B.Co.

MEMPHIS BRIDGE

Adjustments at Center, Intermediate Span.

G. S. Morison Al. Engr.



25. A full report of the laboratory tests shall be furnished, certified by an inspector, accepted by the Chief Engineer.

26. The broken and bent specimens shall be preserved subject to the orders of the Chief Engineer.

27. Notices shall be sent in duplicate to the Chief Engineer at his Chicago office, and to the shop inspector at the works.

28. Analyses shall be made by the manufacturer of every melt, showing amount of phosphorus, carbon, silicon and manganese, and certified copies of these analyses shall be furnished to the mill inspector, who will forward them to the Chief Engineer. The phosphorus and carbon analyses shall always be made. Analyses for silicon and manganese shall be made whenever called for by the inspector. Copies of all analyses, whether made by the request of the inspector or by the desire of the manufacturer, shall be furnished to the Chief Engineer.

29. Duplicate reports in full detail, including reports of chemical analyses, shall be sent to the Chief Engineer at his Chicago office, and also to the shop inspector at the works, not later than the day on which the accepted material is shipped.

30. Two notices of shipment of manufactured material, identifying the melts and dimensions, shall be mailed on the day after such shipments are made, one to be sent to the Chief Engineer at his Chicago office, and one to the shop inspector at the works.

31. Every finished plate, bar or angle shall be stamped on one side near the middle with a number identifying the melt, and this stamp shall be surrounded by a heavy circle of white paint. Steel for pins shall have the melt numbers stamped on the ends. Rivet and lacing steel and small pieces for pin plates and stiffeners may be shipped in bundles securely wired together with the melt number on a metal tag attached.

32. The finished product shall be perfect in all parts and free from irregularities and surface imperfections of all kinds.

33. The cross-section shall never differ more than 2% from the ordered cross-sections as shown by the dimensions on the plans.

34. All sheared edges shall be planed off so that no rough or sheared surface shall ever be left on the metal.

35. Steel for pins more than 4 ins. in diameter shall be hammered steel, and tests shall be made on this steel in accordance with the requirements of Section 22. In such tests an elongation of 15%, and a reduction of area of 30%, given in each of two test bars tested separately, will be accepted as satisfactory, provided the character of the fracture is satisfactory. The bending test required in Section 20 shall be made on pin steel, but pin steel will not be rejected, provided the bar will bend around a circle of a diameter equal to twice the thickness of the bar without cracking. Steel for pins shall be sound and entirely free from piping. All pins in the main trusses shall be annealed before they are turned, and shall be drilled through the axes.

GEORGE S. MORISON,
Chief Engineer.

JANUARY 1ST, 1891.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

625.

(Vol. XXIX.—September, 1893.)

BRIDGE SUBSTRUCTURE AND FOUNDATIONS IN NOVA SCOTIA.

By MARTIN MURPHY, D. Sc., C. E.; M. Can. Soc. C. E.; Pres. N. S. Inst. Sc.; Provincial Government Engineer, Nova Scotia.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The subject of adopting concrete as a substitute for masonry in bridge work has approached such magnitude that the author cannot but be diffident of his power to treat it satisfactorily within the ordinary limits of a paper of this kind. After a few preliminary observations, he will confine his remarks to a notice of the employment of Portland cement concrete as a building material in works coming directly within the scope of his own supervision in the Province of Nova Scotia for the past 10 years, and to what may be considered cheap and effective methods for finding or providing foundations for such structures when under water.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

All that science, skill and experience can, with the progress of time, be expected to achieve in designing and erecting metallic structures to convey railways and public highways over every channel, passage and avenue encountered, is being effected. Yet it is no less obvious that the same degree of attention is not being bestowed on the substructure. And although the iron or steel superstructure may demand more careful thought and more practical application, the substructure is no less important to consider, as it is an ever-varying quantity, just as the heterogeneous texture or uniformity of the ground may happen to vary, or as the nature or stability of the foundation-bed may prove sufficiently solid to support the load it has to sustain.

Safety, durability and economy, coupled with uniformity of design, characterize the typical American bridge, viaduct or roof. The cost of any span will chiefly depend on its dimensions and weight and the place or position in which it is to be erected; competition has so equalized and reduced the cost to a minimum that a reliable estimate is easily obtainable when these conditions are understood and specified. Not so with regard to the economy of the substructure. It too frequently happens that less skill is employed, and hence more waste takes place. The foundations of piers and abutments are too often treated as if fully determinate without due examination; suitable materials within easy distance are occasionally ignored to follow some rigid rule or order of construction, when their employment in other forms might be made to fulfill all the conditions necessary for the erection of rigid, reliable and permanent supports.

The convenience of obtaining a firm and reliable base by the formation of a solid mass of concrete and the facility with which it is made have led to its almost universal adoption, and its expediency as a substitute for stone above ground has been much discussed. Until recently, there were but few good examples of concrete that could equal in value natural stone of the commonest kind. It is now very different, for the daily increasing knowledge which regulates its manufacture has reached a degree of excellence hitherto considered unattainable.

In 1883 concrete was first used by the author as a substitute for masonry in the construction of highway bridges in Nova Scotia, at first sparingly and with hesitation; but of late it has been used largely and with much confidence. Its use for the support of the superstructure

of iron bridges was prompted by necessity, because of the scarcity of materials suitable for ashlar masonry, the cost of transportation, the lack of skilled workmen, and the rapidity with which concrete structures could be erected with ordinary labor. It was not expected that this use of concrete would receive favorable public consideration and it did not. It was treated by the press and by the public as an expensive innovation.

It was alleged that in the climate of Nova Scotia it was an impracticable intrusion and would not suit its intended purpose; and although it could not be said to be a mere experiment, because it had been used so largely abroad, still it was generally commented upon with disfavor. Nevertheless, concrete piers have been erected in the most exposed positions, in the midst of strong currents, without any external protection, where they are exposed to heavy ice floes, to blows from timber rafts and in many instances to undermining by scour, with very favorable results. The climate of Nova Scotia, although not characterized by as wide a range of temperature as that of Quebec and Ontario, is more severe in its effects on masonry and concrete, owing to more rapid and frequent changes in meteorological conditions. In this fitful climate, we have a range of from 15° below to 90° above zero Fahr.; but such alternations have, so far, produced no visible damaging effect; violent blows strike more impotently upon concrete than upon masonry, and it is not so liable to fragmentary slips or segregations because of its monolithic character.

In a paper read by the author before the Canadian Society of Civil Engineers in February, 1888, on "Concrete as a Substitute for Masonry in Bridge Work," and in the observations made thereon, the subject was fully discussed by him and by other members of the society, some of whom were personally acquainted with the work during the progress of construction as well as with its subsequent behavior. It is not the purpose of the author to repeat that discussion here; he may, however, be permitted to refer to it and to offer some supplementary remarks on the results of five years' further experience and on the manner in which concrete work, above ground, then introduced to the notice of the Canadian Society, is standing the test of time.

There have been 147 highway bridges of metal superstructure, resting upon abutments and piers of concrete, built in Nova Scotia within the last 10 years. Forty-four of these have been in existence for a

period of five years; some of them within the influence of the augmented and turbulent tides of the Bay of Fundy, most of them exposed to heavy drift ice and all of them to the extremes of climatic exposure, yet but one failure can be recorded, and that is, no doubt, owing to careless workmanship. The introduction of concrete as a substitute for masonry above the surface in Nova Scotia, has been attended with such results that its employment is being extended and adopted for the renewal of piers of railway bridges, piers that have been so abraded and displaced by clumps of moving ice that renewal in the interests of safety became imperative. There are two 150-ft. iron spans carrying the trains of the Windsor and Annapolis Railway over the Gaspereaux River, resting upon abutments and piers of concrete, recently erected. The piers of the Avon Bridge, on the same line of railway, have been encased by a matrix of concrete, to preserve the ashlar masonry from total destruction. This bridge was supported by eight piers and two abutments of freestone; it consists of nine spans of iron lattice truss, six of which are 160 ft. each, the other three being smaller. Neap tides rise about 24 ft., springs 4 or 5 ft. higher. The bridge was erected in 1879 and had for 10 years been a source of annoyance and expense to the railway company. The water penetrated the body of the masonry during high tide, and not being able to escape as fast as the tide receded, the severe frost operating upon it, through thaw and frost and frost and thaw, lent at every successive reflux its expansive influence to the tottering face stones, forcing them outwards little by little, until the whole mass became so unstable as to necessitate immediate renewal. An envelope of concrete within a timber framework proved a cheap and effective remedy; it has for the last four years withstood all such recurrent vicissitudes, and its present appearance give assurance of future permanency.

The adoption of the various building materials which Nature affords for the purposes of construction requires both practical and technical knowledge. When stone of a suitable nature for building can be had within reasonable distance or at moderate cost, we still prefer it; but where such conditions are absent we may be justified in copying Nature in rock-making and substituting manufactured monoliths in its stead. Concretes will differ in quality according to the care bestowed on the selection of the materials used and the methods by which they are compounded, and until it becomes a specialty

such work can only be satisfactorily done under the eye of the trained engineer.

The plates accompanying this paper give a typical illustration of concrete structures in existence and of works now being erected in Nova Scotia. The following extract is from the author's paper, pp. 81–82, Vol. I, *Transactions Canadian Society of Civil Engineers.*

"The abutments and piers were built within a skeleton framework closely boarded against the face as the work proceeded upwards. They were built of Portland cement rubble concrete, faced with Portland cement fine concrete. The facing of fine concrete was generally 6 ins. in thickness, but varied to a width of 9 ins. in rapid currents, or where liable to more severe usage than is due to ordinary exposure. The Portland cement rubble concrete was composed of 1 part of clean gravel or small stones not exceeding 1 in. in diameter, 5 parts of large stones weighing 20 lbs. and upwards, 2 parts of sand and 1 part of Portland cement. In mixing the concrete, the gravel, sand and cement were turned over three times while dry; water was then added and the materials again turned over at least three times and well agglomerated before being placed in the work. The gravel, sand and Portland cement for the fine concrete were first mixed, to form a matrix or body of concrete, and the large stones of the rubble concrete were placed therein by hand. These stones were placed end upwards, 2 to 3 ins. apart, and the spaces between them grouted up solid with the matrix, to form a compact mass, and any holes or cavities in the works run full flush with Portland cement compo, consisting of 2 parts of sand and 1 of cement. The fine concrete facing was kept at least 6 ins. higher than the rubble concrete, and united with it so as to form one homogeneous mass. In every instance the top of the pier was finished with fine concrete for a depth of 1 ft. 6 ins., and the shoes of the iron truss posts were placed thereon without the usual bridge seats of stone.

"The concrete work for the last three years (now for the last eight years) has been executed by the Government's own engineers and workmen." * * * "It was considerd more advisable to carry out the work by men working by the day and trained under proper supervision, until they became sufficiently skillful, and as interested as the engineer in the success of the undertaking."

Objections are frequently taken against the use of large stones within the concrete body, because homogeneity is said to be an essential feature to obtain the best results. The assumption that the bond between the large stones and the concrete is not so great as in the concrete itself is not an established one. Although tests by compression on small concrete columns give varying results, according to the kind of stone

and other materials used, it is not difficult to observe that the planes of cleavage are in the concrete itself, and the results compared with those of similar tests on similar kinds of stone broken to the size of Macadam are not at all so much in favor of the smaller intermixture as would warrant the exclusion of the large stones. The desirability of the employment of large stones in an economical sense will be determined by the supply available. In Nova Scotia they too frequently encumber the ground. Their adoption lessens the price of concrete more than 30 per cent. Ten 400-lb. barrels of Portland cement will build, on an average, 8 to 9 cu. yds. of concrete, and all the intervening intermixture of concrete will be rich in cement. The cost of concrete work in Nova Scotia has been from $5.50 to $6.50 per cubic yard for piers and abutments, and from $7 to $8 for concrete work in arched bridges.

The concrete work forming the arches of the small highway bridges shown by illustration was first built in courses radiating in the same manner as dressed stone in courses for arch work, so as to prevent any horizontal tendency to set flaky as the work went on. Each course was molded on the lagging of centers by securing thereon a board in the true radial line between soffit and extrados, and the concrete was placed there in its final position to form the course. When sufficiently set, the board was removed and placed again for the next succeeding course. A setting templet, the same as masons make use of when laying voussoirs or arch stones on centers, readily gave the inclination of the board. The foreman in charge was cautioned not to permit any course to be partially filled up and allowed to set before the whole was completed. In this way the course was expected to have the same consistency throughout. The concrete used in the arches was of the same admixture as described in this paper as "fine concrete." Recently, however, the arch work was built *en masse*, an ample supply of material being first produced, and the work, once commenced, was proceeded with as rapidly as possible to completion.

Generally speaking, suitable materials for the aggregates are to be found throughout Nova Scotia in a naturally fit condition for concrete-making, without preliminary treatment, except occasional washing. River and seashore gravels and sands from the denudation of granite, quartzite or whinstone rock from Cambro silurian strata are quite common, while clean pit gravels from old river-beds or from moraines are frequently available further inland. In all cases care was taken

that the aggregates were not used unless clean, free from earth or loam and from all organic substances. Nearly all the cement used was of "White's brand" of English Portland. It was always tested for tensile strength, weight, fineness and hydraulicity.

That no rigid rule or uniform order of construction of bridge substructure ought to be invariably followed when forces of conflicting elements have to be dealt with is well exemplified by the failures of structures erected over the rivers within the tidal influence of the Bay of Fundy. The author is not aware of any one instance where an ashlar masonry structure under such conditions of tidal influence has not been more or less a failure. The railway bridge crossing the Avon River at Windsor, already noticed, is not the only instance. The same remarks might be applied to piers or bridges carrying the Intercolonial Railway over the Shubenacadie and Sackville rivers, all of which have had to be renewed since their erection; while within the limits of those phenomenal fluctuations, characteristic of the Bay of Fundy, concrete made from aggregates obtained from off the shingle beaches close at hand has, so far as it has yet been properly employed, given satisfaction.

In the paper submitted to the Canadian Society in 1888, already alluded to, the history, theory and manufacture of Portland or artificial cement, and its application to bind the usual aggregates into concrete *en bloc*, was more fully noticed and discussed. The purpose here is to point out how it is behaving as a substitute for masonry in the climate of Nova Scotia. But, it may be asked, what is the justification for the employment of concrete at all above ground in lieu of stone? The fact that walls and bridges are produced which perform the service expected of them at a much less expense than masonry; that by the utilization of materials otherwise valueless, such as the shingle of the beaches and streams, and the boulders encumbering the surface, permanent bridges can readily be built with the assistance of ordinary labor; that by the employment of concrete, limited means will yield more desirable results; that evidence exists that such adoption would secure at low cost works of great efficiency, is sufficient to justify the use of concrete as well as the introduction of the subject of its adoption here.

Concrete work should not be proceeded with during the extremes of hot or of cold weather, without protection from such extremes. An

even temperature of about 60° Fahr. is the most desirable for its manufacture and use. During summer heat in our Canadian climate, the walls should be covered immediately after the introduction of the concreting material, and occasionally sprinkled over with a hose or through a finely punctured nozzle of a watering-can. Injurious effects from freezing are still more to be avoided. It is better to desist from concrete building early in the month of October. It is requisite that the concretionary process should go on with extreme slowness on the outer or exposed surface of concrete walls. The interior of the mass will set slowly; the induration should extend equally slowly in all directions so that the solidifying condition may be simultaneously reached throughout the body, and that the cohesive attraction and crystallization may be uniformly progressive.

Foundations.

The general principles of dealing with foundations where water offers no impediment to the execution of the work will not be noticed here. The remarks submitted will be confined to the methods devised and the practice employed in providing firm and reliable footings upon which to rest abutments, piers and cylinders, that support metal superstructure of railway and highway bridges built under the supervision of the writer. They may be classified thus :

First.—For cylinders, to rest on a friable rock river-bed, as at Avon Bridge, Windsor.

Second.—For cylinders founded on rock partially covered by shifting sand, as at Board Landing Bridge, Truro.

Third.—For cylinders to rest on a hard boulder, clay bottom, intermixed with large boulders, as at Bridgewater Bridge.

Fourth.—On soft alluvial bottom, as at Lockeport Bridge, Lockeport.

Fifth.—On soft clay bottom, foundation for circular swing pier, as at Little Bras d'Or Bridge, Cape Breton.

Sixth.—On piles cut 20 ft. under water for foundations of cylinders, as at Victoria Bridge, Bear River.

Seventh.—Within caissons to rest upon piling, as at Sutherland's River Bridge, Eastern Extension Railway.

Eighth.—With coffer-dam where water is excluded, as at Restigouche Bridge, Intercolonial Railway of Canada.

Ninth.—Within a coffer-dam where canvas is made use of instead of puddle, as at Mill Stream Bridge, Intercolonial Railway of Canada.

The Avon Bridge Foundations (*Plate No. 1*).—The substructure consists of five pairs of steel cylinders of from 35 to 48 ft. in height. They are each 5 ft. internal diameter, and are filled with concrete. The shells are $\frac{3}{8}$ in. in thickness; they are coupled together by laced beams and sway bracing. The coupling is sheathed over, making the pier dumb-bell shape in section. They are capped like doric columns. Two rolled I beams connect them over caps and form a base for the bridge seats and iron trusses to rest upon. This method of coupling the columns is employed, to unite their strength in resisting impinging blows of ice, as well as to keep the ice floes from getting caught in the bracing.

The columns rest upon limestone rock, carboniferous, and are secured to it. The manner of fastening the columns to the rock under water is, the writer believes, original, and he wishes to place it on record here. Limited means suggested its trial, and the result seems to justify its practice. A profile of the bed of stream, with depth of water at low tide, is as follows:

Commencing at the eastern or Windsor side of stream, the first pair of columns would be in 4 ft. of water, the second pair in 9 ft., the third in 9 ft., the fourth in 12 ft. and the fifth in 14 ft. of water. Neap tides rise 28 ft.; springs, 4 or 5 ft. higher. There were some loose boulders and a shifting sand, but as the width was contracted by the foundation work, the current removed the latter. The stones or boulders were readily removed by ordinary hand grappling. Cribs of wood were put together on the shore, and partially filled from ballast floors up, with sufficient stone to submerge them and preserve their buoyancy for floating to their destination. Two voids of 8 ft. square were left in each crib, to receive the cylinders. These cribs were floated into place at low water and sunk by additional stone ballast, so that the top stick stood clear over low water when sunk, and the voids were fairly over the sites to be occupied by the cylinders. The voids were next boarded over and the centers of cylinder positions marked upon them. From those centers a radius of 2 ft. 6 ins. gave the position or shell of each column. Next, within the radius nine equi-distant points were marked on the boards, and a large auger hole bored through the floor at each point, thus defining the periphery or outer

shell of the column when in place, and the position of nine dowels to be placed within it. The holes in the floor marked the position of the drill, and the floor itself acted as platform for the three men to work on, in the ordinary method of rock drilling. The workmen had no difficulty in drilling nine holes into the rock in this way, from 2½ to 3 ft. deep, nor in dropping dowels of 2-in. round iron into the drill holes. Thus there were within each tube nine iron dowels of 2 ins. diameter, standing to a height of from 2 to 4 ft. The cylinder was then lowered to its resting place, and the inside of the tube, as well as the 8 × 8 ft. void outside, filled up with concrete.

The method employed for placing concrete under water between the iron dowels proved very effective. Bags, made of rough brown paper well stiffened with glucose, were employed and slipped into the water over the required place of deposition. Each bag held about one cubic foot of concrete; smaller ones were used between dowels. The bags were quickly made up and dropped one after another, so that the one following was deposited before the cement escaped from the former one. The paper was immediately destroyed by submersion, and the cement remained; it could not escape. The bags cost $1.35 per hundred, or 35 cents per cubic yard.

The same practice adopted for the foundation of Avon Bridge can be employed in from 15 to 18 ft. of water. With the help of a diver it can be carried on in greater depths. The writer claims that the means employed to put in the foundations of Avon Bridge have been cheap and practical and effective, and the results have fully justified their adoption.

The work in connection with foundation and crib work was commenced by the Government during the first week in May, and continued without obstruction, accident or intermission. The first sections of the first pair of cylinders were set in place by the Dominion Bridge Company on July 19th, and the other four pairs were in position August 19th following. As each bottom section was fixed it was immediately filled with concrete, and levels taken on it and forwarded to the Dominion Bridge Company, so that the exact height of each tube to the top might be given to the men in the workshops.

Plate II illustrates the means adopted to obtain foundations for two pair of tubes to support the metal superstructure of Board Landing Bridge near Truro. The bridge crosses Salmon River before it

discharges into Cobequid Bay. The bed of the stream consists of quicksand or fine silt overlying a rock bottom of new red sandstone to a depth of from 5 to 7 ft. Neap tides rise 15 ft.; springs, about 18 ft. Enclosures such as coffer-dams or caissons, to exclude the water and the silt, would be too expensive, and dredging without such protective aid would be impracticable. The problem then became one to find, with the least possible expenditure, a solid bearing for tubes or for concrete or masonry piers of sufficient lateral strength to resist such heavy ice floes as run with the stream during freshets or during the "ogres" or "bores" so characteristic of the tidal rivers emptying into Cobequid Bay or into the Bay of Fundy. The strata being of a yielding semi-fluid nature it was quite practicable to sink the cylinders by dead weight to the rock, or to sink them by the pneumatic process and pump out or force out the quicksand. It was, however, considered that a greater lateral degree of resistance should be provided, to resist the ice jams, than the tubes and their connections could afford in this case. Something stronger and more cumbrous was deemed preferable.

Two rows of close piling, one on each side of foundation, along the longitudinal direction of the pier, were first driven, between wales, to the rock by a small pile-driver; the up and down stream ends of the parallel rows were left unconnected. The width of the stream was narrowed by the piers of the old bridge and by the new work and contracted the water-way so as to create a current of much greater intensity, and this accelerated flow was made to flush and scour out the sand, by directing it through the piled enclosure. Plate III fairly illustrates the method of getting rid of the quicksand. A mattress of brush and small stones was next lowered to the rock; the sheet piling of the ends of the enclosure and two clumps of piles to found tubes upon were next driven through the mattress to the rock, and the whole rectangular block filled with stone and brush to the level of low water. There are no marine borers about the littoral waters of Cobequid Bay, the water is too muddy; they would be sealed up in their burrows by the silt. The tubes were founded as shown by Plate II and filled with concrete.

Plate IV shows the method of preparing foundations for cylinders, the bottom being a hard boulder clay intermixed with large boulders. Bridgewater Bridge carries the highway traffic from the main street of

the town of Bridgewater over the La Have River to the railway station. The abutments are of granite masonry. The piers are built of unusual strength, to resist blows from rafts of timber, or the possibility of being carried away by jams of logs that are occasionally set adrift by freshets from the booms in the mill ponds up-stream. The foundations of each pier support three steel cylinders of 4 ft. internal diameter, each filled with concrete. There is nothing remarkable in the plan adopted except that it shows a cheap and effective method of dealing with a bottom of so refractory a nature, without the aid of coffer-dams or caissons. The bridge is near the "head of the tide"; a large body of fresh water passing through prevents damage to the submerged timber by the *teredo* or the *limnoria*. The two granite abutments and retaining walls out of stream cost $5 717, while the foundations of the two piers within stream, up to the level of low water, cost $2 010. The plan submitted will illustrate the manner of construction. The masonry of the abutments was let by contract at $8 per cubic yard. The work on the piers under water was performed by "day's work."

Plate V shows the method now being employed for constructing the foundations for Lockeport Bridge in the County of Shelburne. The bridge is to convey the traffic of the highway and of a narrow-gauge railway from the town of Lockeport, Lockeport Island, across a tidal armlet to the main land. The roadway crosses a small island with from 400 to 500 ft. of shoal water on either side and a channel of about 300 ft. in width, available for floating vessels through when launched from ship-building yards further up. The bottom, for a depth of 16 ft., is very soft, peaty mud overlying stiff clay. The water is from 3 to 4 ft. deep on the flats and about 10 ft. in channel at low tide. Neap tides rise 6 ft.; springs, 8 ft. The roadway over the flats is being constructed upon a broad base of mattresses and faggots of brush, and the channel is being bridged with a steel swing bridge to revolve on a circular concrete pier and two fixed spans supported by steel tubes. All rest upon artificial foundations of piling.

The *limnoria lignorum* is active in the Harbor of Lockeport, showing the necessity of having the timber piles protected by an outer wall or covering of concrete. The hexagonal block of sheet piling and the rectangular blocks of piling round the tubes are driven merely to retain the concrete. The plan shows all other details of construction for foundations and for substructure.

The plan adopted for dealing with the foundations of Sutherlands River Bridge, Eastern Extension Railway (see Plate VIII), could be also fittingly selected for the foundations and substructure of Lockeport Bridge. A careful examination of the conditions and costs showed, however, that a saving of from 30 to 35% would be effected in favor of the method now being employed at Lockeport, and the cheaper plan was accordingly followed. The cost of foundations and substructure of the circular pivot pier and for the four pair of tubes to support the two fixed spans, up to the level of low water, will not exceed $5 000.

Plate VI shows foundations and circular pier of a swing truss, built over the navigable channel of the Little Bras d'Or, Cape Breton. The bottom or bed of channel is of soft mud and clay, the denudation of the carboniferous strata of the district. The principal feature to be noticed is the plan adopted for building the pier to support the swing bridge and securing foundations therefor.

All round the site of this bridge, as well as its environs, is a favorite haunt of the *teredo navalis* or the *teredo norvegica*, Spengler, more probably the latter. The bridge consists of one swing span, 162 ft., and a fixed span of 80 ft. To better subserve the requirements of navigation, the pier on which the swing revolves stands in 28 ft. of water at low tide. The pier consists of a center cylinder 4 ft. in diameter, surrounded by six cylinders of 3 ft. diameter each, all coupled together above water level with laced beams. The pivot on which the swing revolves, rests on the center tube, and the six other tubes support a track resting on rolled I beams covered with $\frac{3}{8}$-in. plate. The foundations of the tubes consist of clumps of piles, cut off at level of the bed of the stream by machinery, one pile in the center of each clump having been cut about 6 ft. higher up. The tubes are filled inside with concrete to top, and outside with concrete and stone to a height of 15 ft. from the bed of the stream. The outside piers and abutments are built of Georgia yellow pine, creosoted by Eppinger & Russell, Brooklyn, N. Y. The whole work cost $19 000.

Plate VII illustrates the system employed for obtaining foundations for the fixed spans of the bridge constructed in 1888 to replace the Victoria Bridge, Bear River, which consists of a swing span 160 ft. in length, two fixed spans of 125 ft. each and one of 100 ft. The swing span revolves on a circular pier 24 ft. in diameter, constructed entirely

of concrete. Each pier for the fixed spans consists of two wrought-iron cylinders, 5 ft. each in diameter, filled with concrete, coupled together by laced channel beams and lateral bracing, and sheathed between main tubes, to prevent lifting or displacement by ice floes. It is, however, the circular or concrete pier that comes most properly within the bounds of these remarks. There is 18 ft. of water at ordinary low tide; springs rise 29 to 30 ft. The *limnoria lignorum* is here so active that the bearing power of piles, or of timber submerged below the level of low water, is, where exposed, affected, if not destroyed, within six years. The supports of the old wooden bridge had to be renewed twice within a period of 12 years. The new bridge is placed immediately above the old one, and if founded on piles similarly unprotected would be no more reliable. The foundations are so liable to scour by the rapid running tides or ogres, so characteristic of the Bay of Fundy, on loose gravel deposits, that piles were considered safer to found upon. For these reasons, as well as for one no less obvious, viz., limited means, it was decided to adopt piles driven 3 ft. apart at centers over the whole base of pier, and to protect them with a circular envelope of concrete 3 ft. in thickness. The hexagonal circuit of close piling shown by figure No. 7 is driven merely as a mold to retain the outer wall of concrete while it is being erected. The piles were cut off at the level of low-water spring tides, the intervening spaces between them filled up with small stones, and the usual platform, 12 x 12 ins. timber, framed thereon, thus completing the circular pier up to the level of low water. The concrete superstructure from that point upwards to finish is a frustrum of a cone, having a solid vertical central pillar 4 x 4 ft. to support the pivot and four walls, 2 ft. 6 ins. each in width, radiating therefrom to the outer circular wall, or periphery, which is 2 ft. 6 ins. wide at top and increases downwards with a batter of 1 in 8 ins. The four voids thus left in the body of the prism have vertical sides to within 4 ft. of the top, where they corbel to an apex and are covered with 2 ft. of fine concrete. The columns in deep water supporting the fixed spans rest on clumps of piles cut off at the bed of the river by a circular saw, two piles being allowed to stand up within the body of the tube, to prevent displacement. The spaces outside the tubes to the sheet piling, as well as within the tubes, are filled with concrete, outside to level of low water and inside of the tubes to top. The cost of the bridge approaches and mooring piers amounts to $52 000.

There is not much difficulty experienced in cutting piles under water in the same plane, and at any desirable depth up to 30 ft. Such arrangements can be made above the water level as will ensure their being cut off one by one, perfectly level below. The outer rows of sheet piling having been driven and cut off close to the wales at Victoria Bridge, served as a bearing or platform to rest the framework of pile-driver upon, to cut the inner or bearing piles as close to the bed of the river as the surface of ground would allow the circular saw to work. The shafting of the saw can run in pedestals, set in a frame standing vertical, or can be set along the leaders of the pile frame and adjusted to cut at the required depth below the surface of the water. A circular saw of 3 ft. diameter, with shafting, $2\frac{1}{2}$ ins. diameter, set in a pile frame and worked from a pulley off vertical shaft, with a twist in the belt to change the direction of motion, will freely cut piles to a depth of 30 ft. below the water level. Care must be taken to have the platform on which the machine is moved along as the piles are cut one by one, level, so that the saw working below will enter every pile and cut them off at the same uniform level all round. The belting is run by an engine worked from a scow, and can be made, by the application of a lever, to work in a rising or falling tide without slip or displacement. When well directed by a skillful mechanic, each pile can be cut off in 20 ft. of water in 25 minutes, including the time lost in shifting the machine from one pile to another.

Plate VIII represents the method employed for constructing foundations and substructure of Sutherlands River Bridge, Eastern Extension Railway. This bridge carries the line of railway over a shallow estuary into which Sutherlands River empties at the head of Merigomish Harbor. The bottom is of a semi-fluid lacustrine nature, consisting of silt and peaty deposits for a depth of from 8 to 16 ft. At low tide there is not more than from 2 to 3 ft. of water on the flats, upon which the railway is carried by an embankment resting on faggots of wattle and brush. As the flow of tide is thus impeded, a greater current is created in the channel, over which the bridge of 160-ft. span is built. There is now 10 ft. depth at low water in the channel. Neap tides rise 5 ft.; springs, $6\frac{1}{2}$ ft. The teredo is found boring in submerged wood in the harbor, and its appearance was feared here. In this case artificial foundations had to be provided, in a very soft, yielding strata, liable to scour, and to the attacks of those destructive mollusca.

A row of close piling was driven along the face and around the exposed ends of each abutment, and bearing piles at 3 ft. apart centers, under the base of the masonry prisms. These piles were all cut off level by a circular saw 8 ft. below low water. A water-tight caisson, built on shore, launched and filled with ashlar masonry as high as its buoyancy would permit, was floated into its true position, over the piles, and sunk by the addition of more masonry until the abutment was clear of water. After the abutments were completed rip-rap was carefully placed all round the exposed timber, as is shown by the illustration.

Plate IX and the following extracts are taken from the "History of the Intercolonial Railway," by Sandford Fleming, Esq., Chief Engineer, C. M. G., pp. 163–165. The writer of this paper was the contractor for the foundations and substructure.

"The River Restigouche constitutes the boundary between Quebec and New Brunswick. The railway bridge connecting the two Provinces is the only bridge which crosses the river. It is situated below its confluence with the Metapedia. After emerging from the contracted valley through which the Metapedia flows, the railway turns almost at right angles, to follow the Restigouche. The main stream for some distance is hemmed in between high steep hills, rising abruptly to a height of from 500 to 700 ft., and the sudden change in the direction of the railway necessitates the construction of the bridge on a skew of 45°."

"The hills are composed of a metamorphosed slate, much contorted and so tilted that the direction of the cleavage is not easy to determine. The river takes the direction of the strike and has, no doubt, shaped its course from denudation. Blue clay underlies the gravel in the bed of the river, but it is undoubtedly local."

"Soundings and borings were made through the ice, early in 1869, which led to the opinion that the bed of the river was rock, overlaid with some inches of gravel. But it was found that stones imbedded in gravel were the hard substance met, and that the solid rock was at a much greater depth. The outcrop of rock on both sides of the valley suggested that the stone in the gravel was rock *in situ*. Subsequent borings, however, showed the gravel to extend from 7 to 10 ft., underlying which plastic blue clay is found."

"At Pier No. 1, rock was reached at 53 ft. under the summer level of the river; at Pier No. 2, at 75 ft.; at Pier No. 3, at 62 ft., and at Pier No. 4, at 54 ft.

"Accordingly, piling was necessary in all the foundations, except for that of the easterly abutment, which was built on the rock. The

work of piling was continued throughout the winter, that season being suitable for this operation, the ice forming a platform for the machinery. The coffer-dams were protected by triangular-shaped cribs to act as breakwaters, so constructed as to prevent injury to the works from the ice."

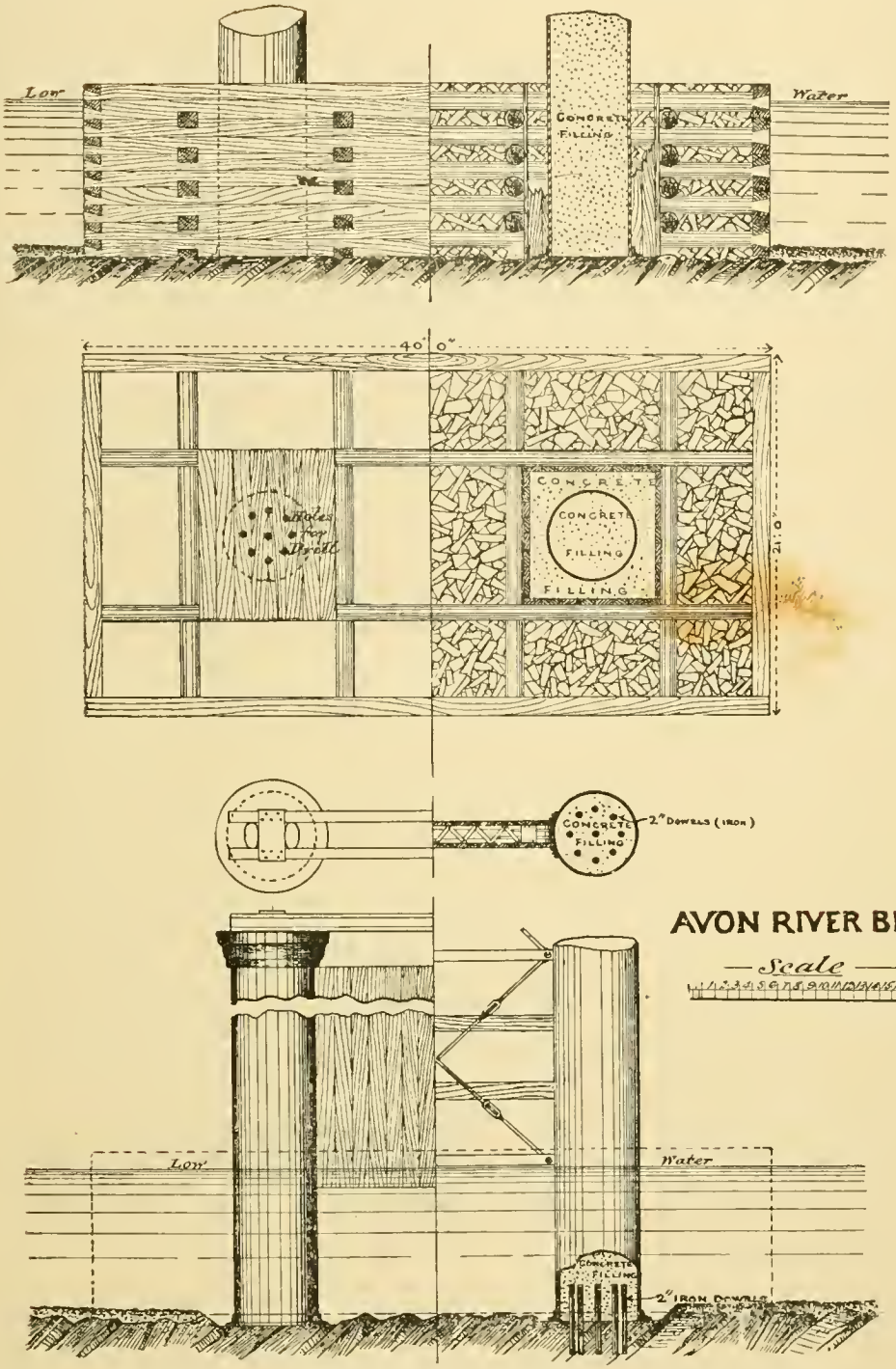
"The pumping was effected by five engines, with an aggregate of 70 H. P. Centrifugal pumps, capable of discharging nearly 6 000 galls. per minute were used. Owing to the stratum of gravel, and the heavy flow of water, the excavation was performed with difficulty. The pier foundations consist each of close square piling, enclosing an area of 102 x 16 ft., with four rows of intermediate piles, 3 ft. apart. The space between the piles was filled with concrete, and a platform was constructed upon them 8½ ft. under water, so as equally to distribute the weight of the superincumbent masonry. Much difficulty was experienced in the execution of these works in a deep and rapid river."

"The pile-driving, of more than 60 000 linear feet of timber, was carried on almost continuously from August, 1872, until April, 1874. Ice begins to form in this river in November, and although the rapids of the river remain for some time open, where the current is slight, ice sufficiently firm to carry a man will form in 24 hours. From November until March, but little rain falls, the thermometer ranging from 32° above to 32° below zero. The average, during the five years occupied in constructing the bridge, was slightly below zero. A change in the weather, when the winter sets in unusually early, accompanied with rain, will occasionally raise the water and break up the ice, producing 'ice jams.' The Metapedia is especially liable to these incidents; in the Restigouche they are not common. The low temperature as a rule, from November to March, produces ice from 2 to 4 ft. thick, and about the end of March it reaches its maximum strength. Moreover, the ice is not confined to the surface of the river. As in many northern localities, anchor ice is developed to a great extent, sometimes to double the thickness of the surface ice. It is not, therefore, surprising that at the end of winter a sudden thaw, raising the water of the main stream and setting adrift the whole winter ice, should produce astonishing results. Floating down stream, these masses of ice meeting with obstructions will pile one on the other, until a 'jam,' completely across the river, is produced."

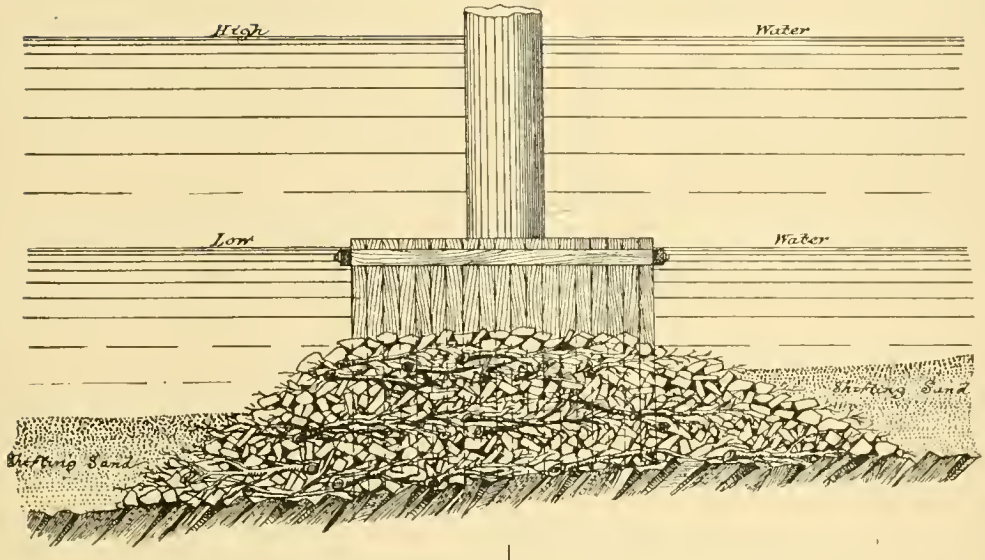
"The water thus dammed back will in a few hours rise to a height, sometimes of 20 ft. The 'jam' ultimately gives way, and a moving mass of ice, water and uprooted trees is borne onwards, often with a current of 7 or 8 miles an hour."

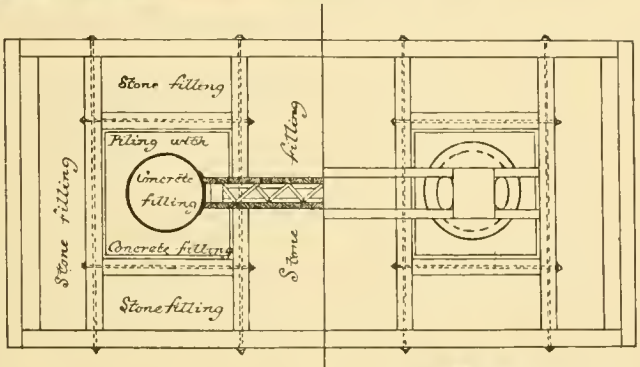
"The river Restigouche is liable not only to these 'ice shoves,' but to occasional freshets; the most marked of which, the 'spring freshet,' occurs yearly with regularity at the end of May or beginning of June.

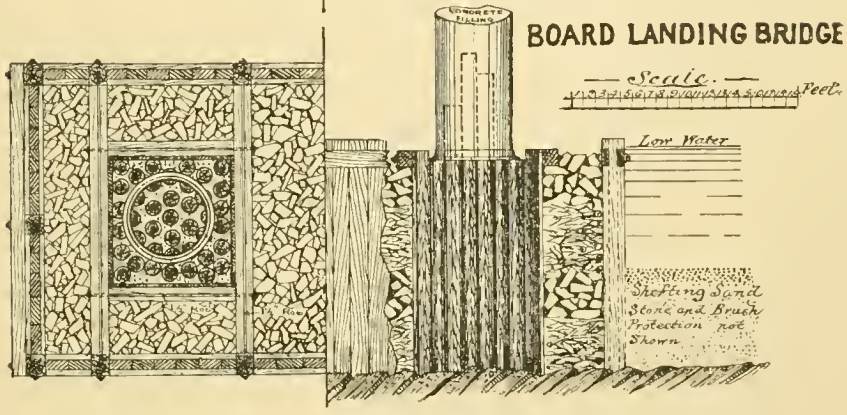
VOL. XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE I.



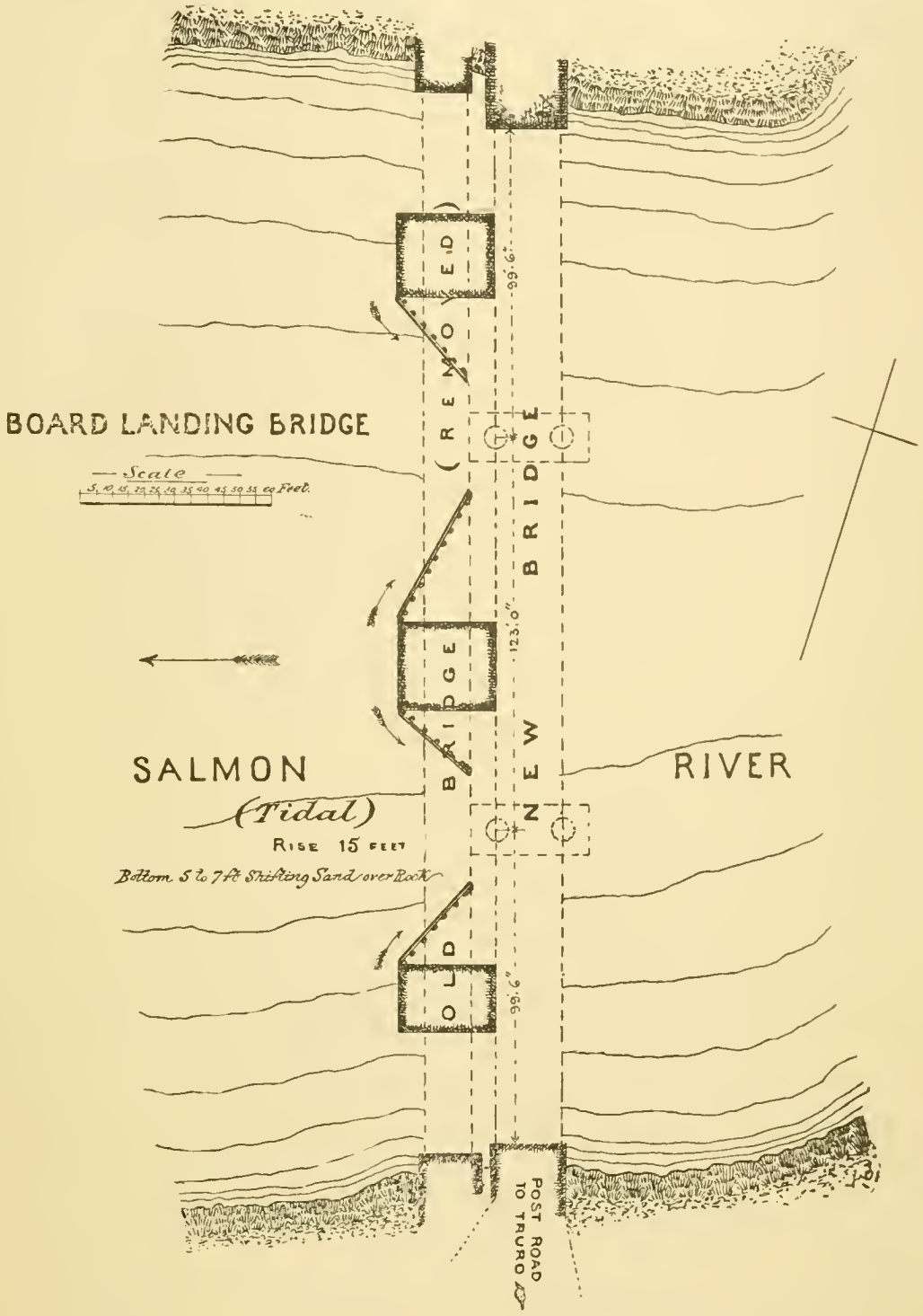
VOL. XXIX, No 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE II.

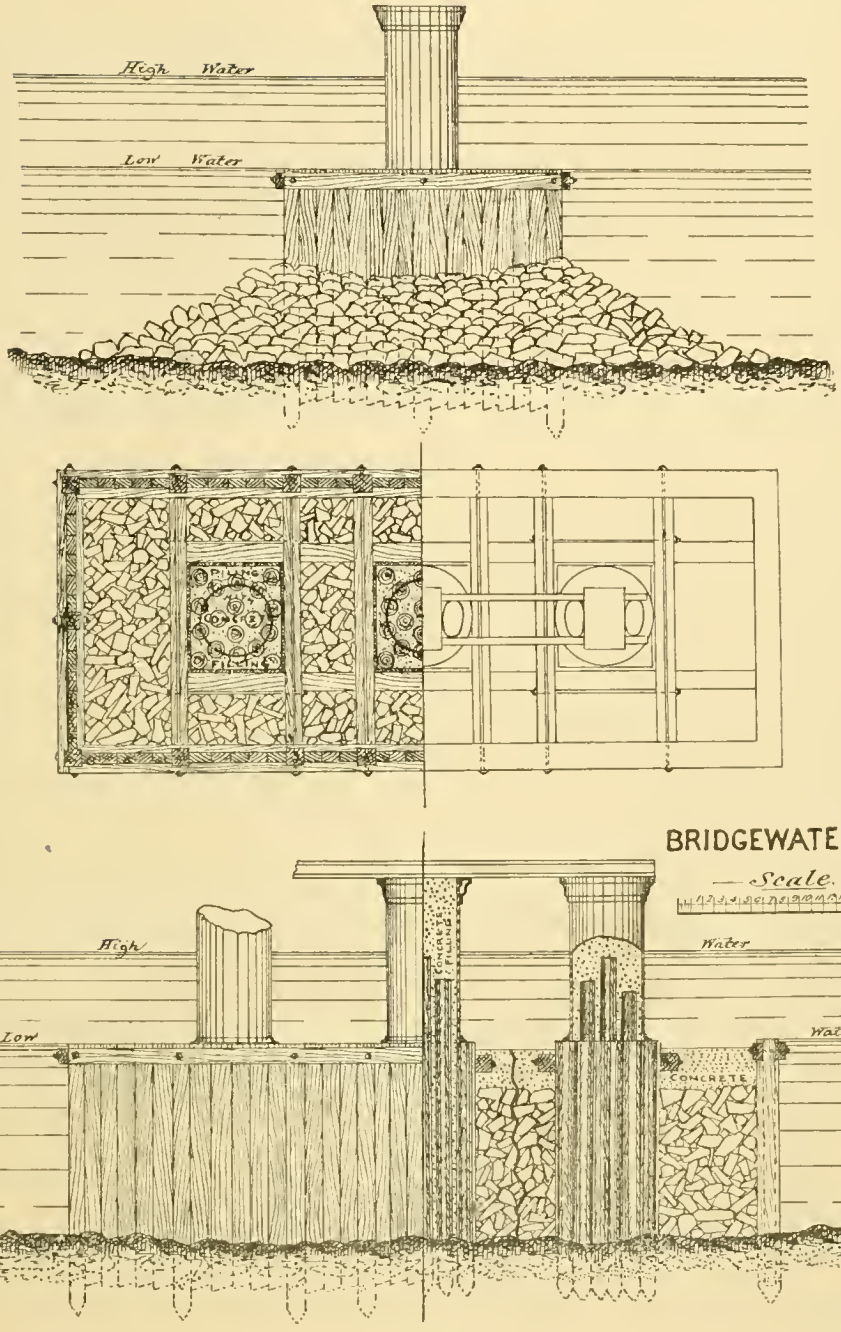




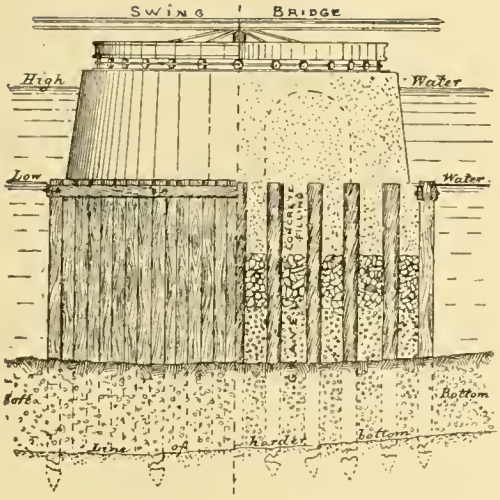


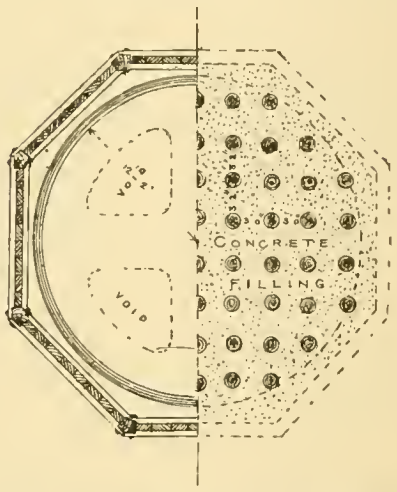
VOL. XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE III.

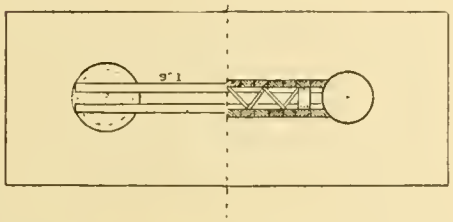


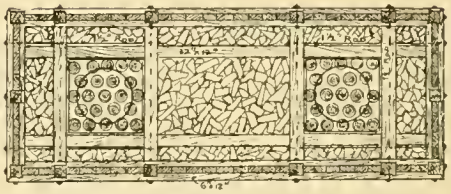

High Water
Low Water
FILLING
BRIDGEWATER BRIDGE
Scale.
Feet
High
Water
Low
Water
CONCRETE
CONCRETE

VOL. XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE V.



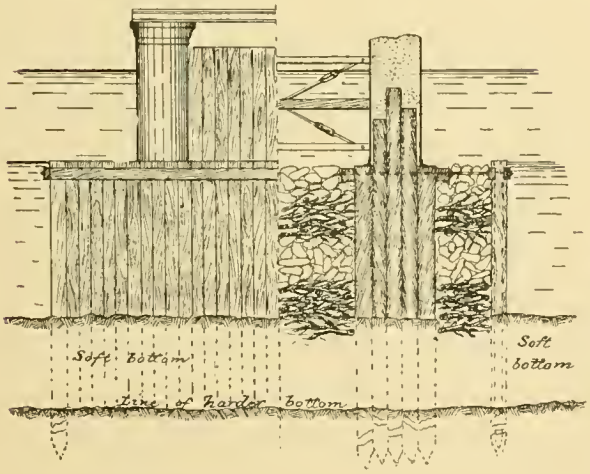


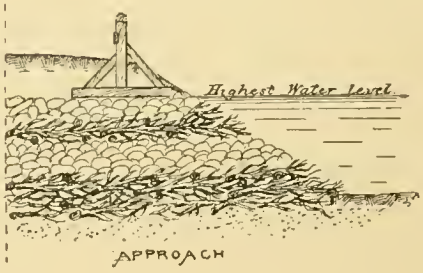


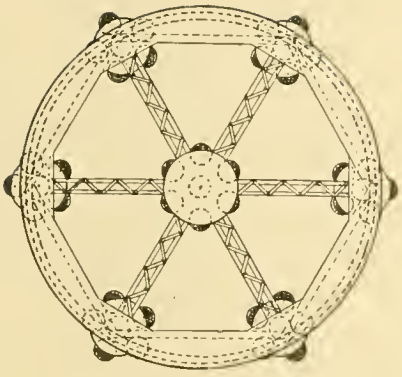


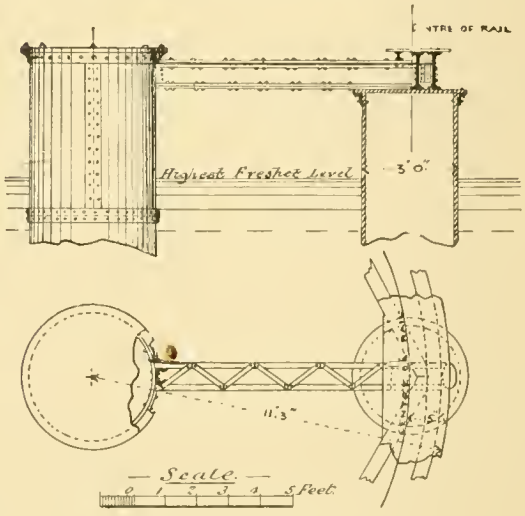
LOCKPORT BRIDGE

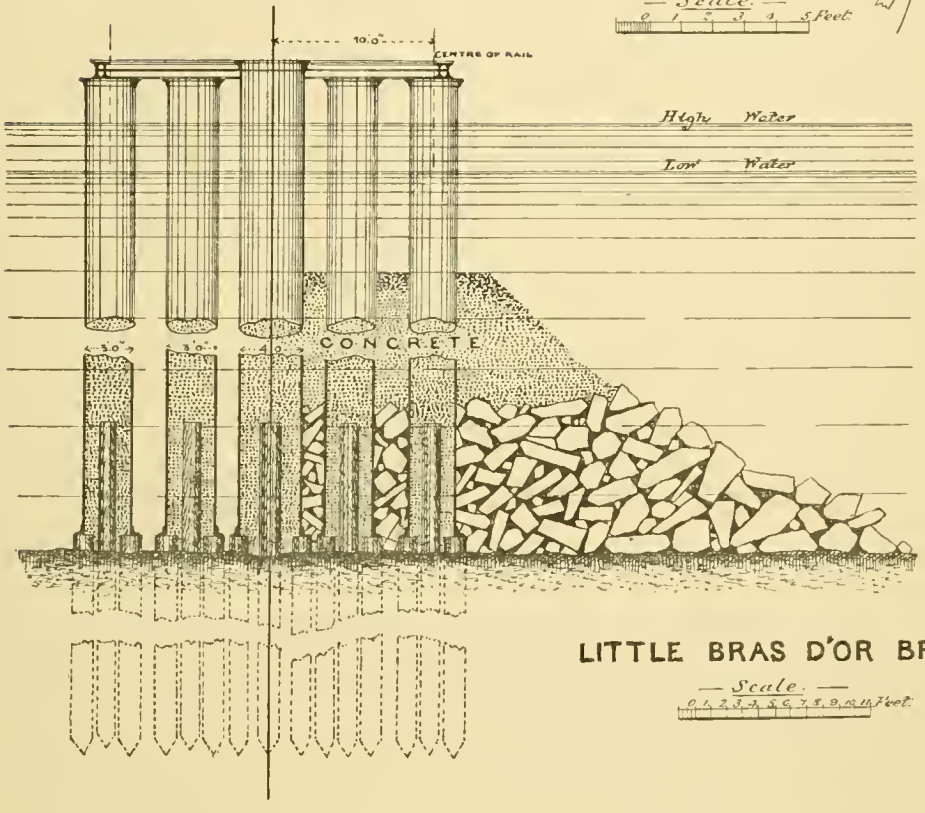
SWING 114'— 2 SPANS 85







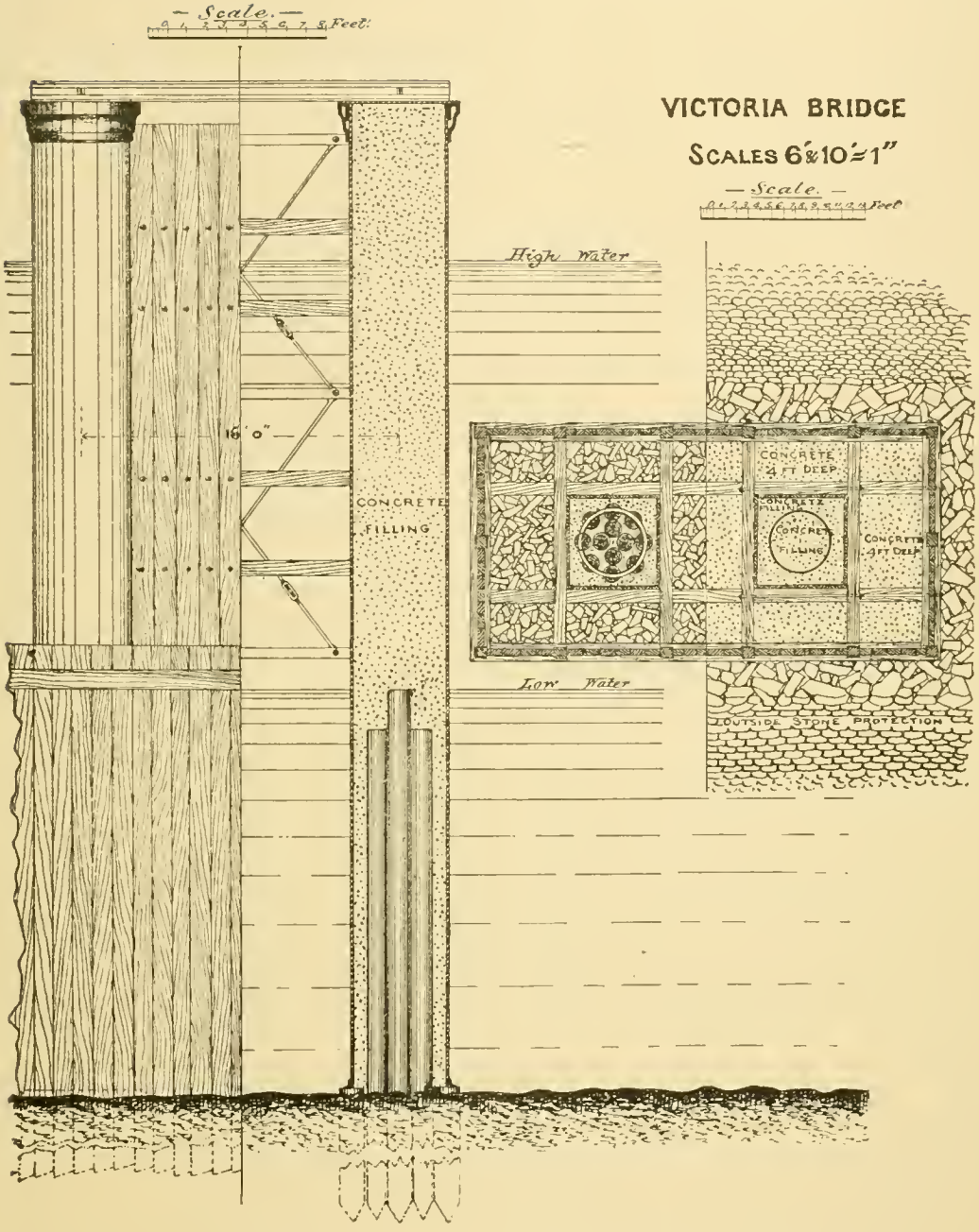




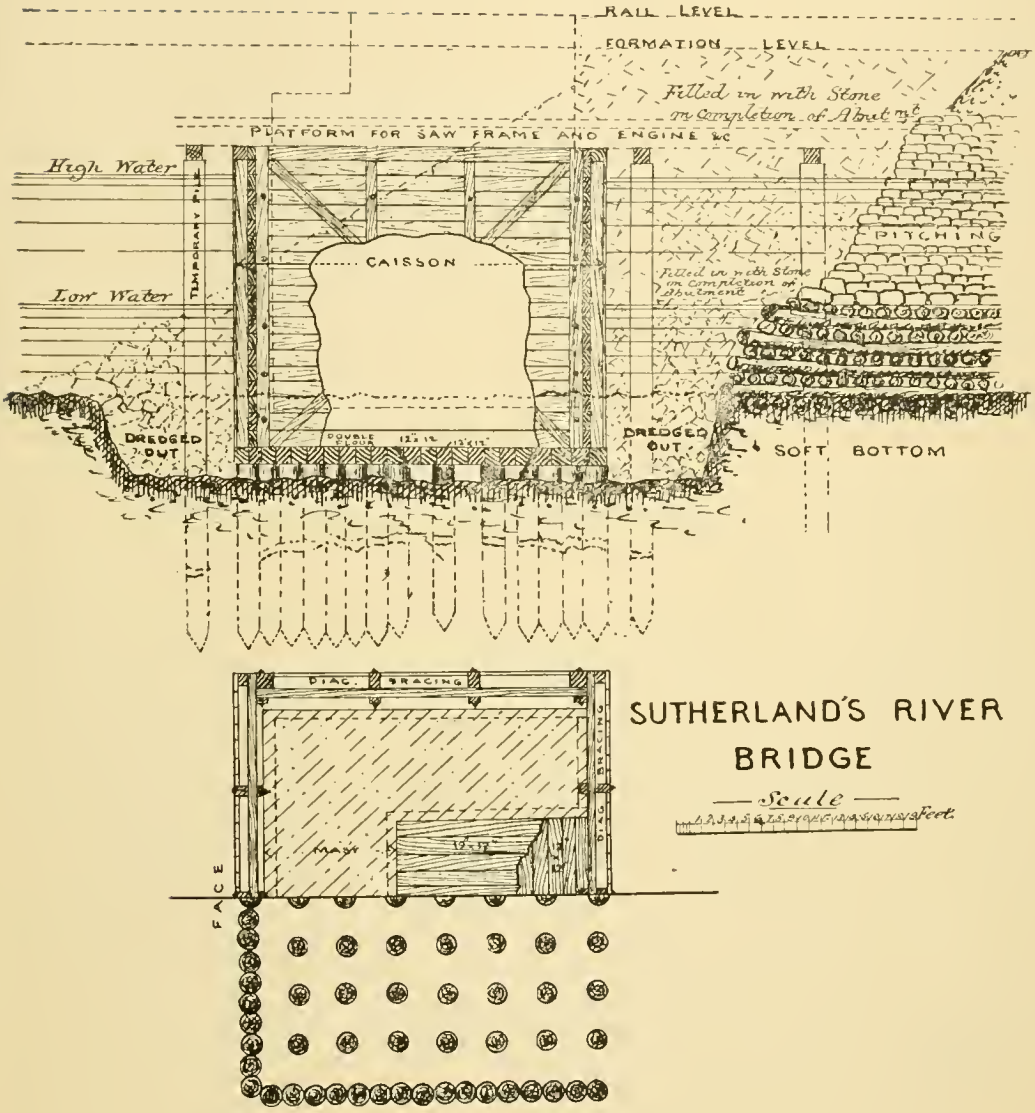
LITTLE BRAS D'OR BRIDGE

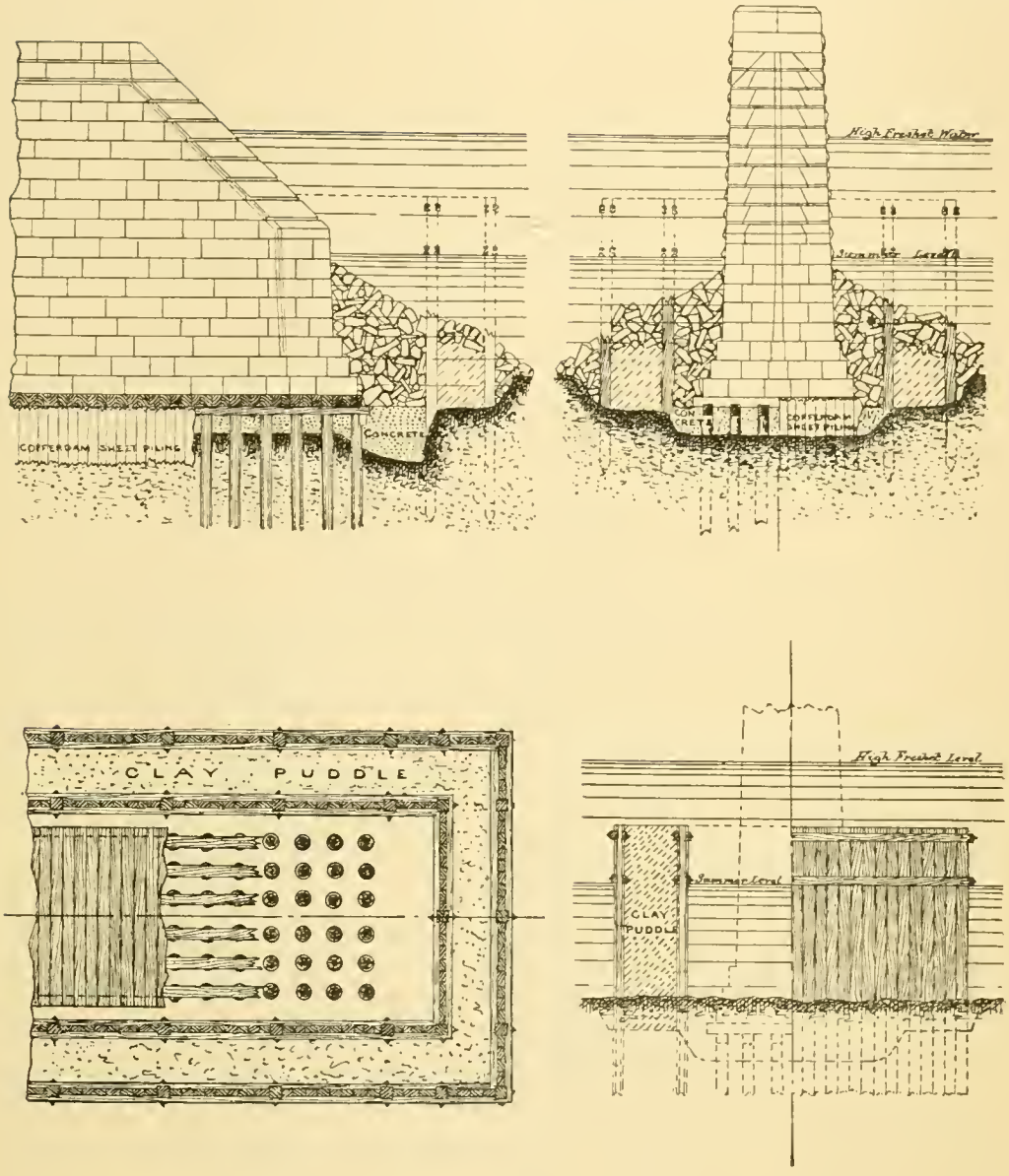
Scale.
0 1 2 3 4 5 6 7 8 9 10 11 Feet.

VOL. XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA
PLATE VII.



VOL. XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE VIII.



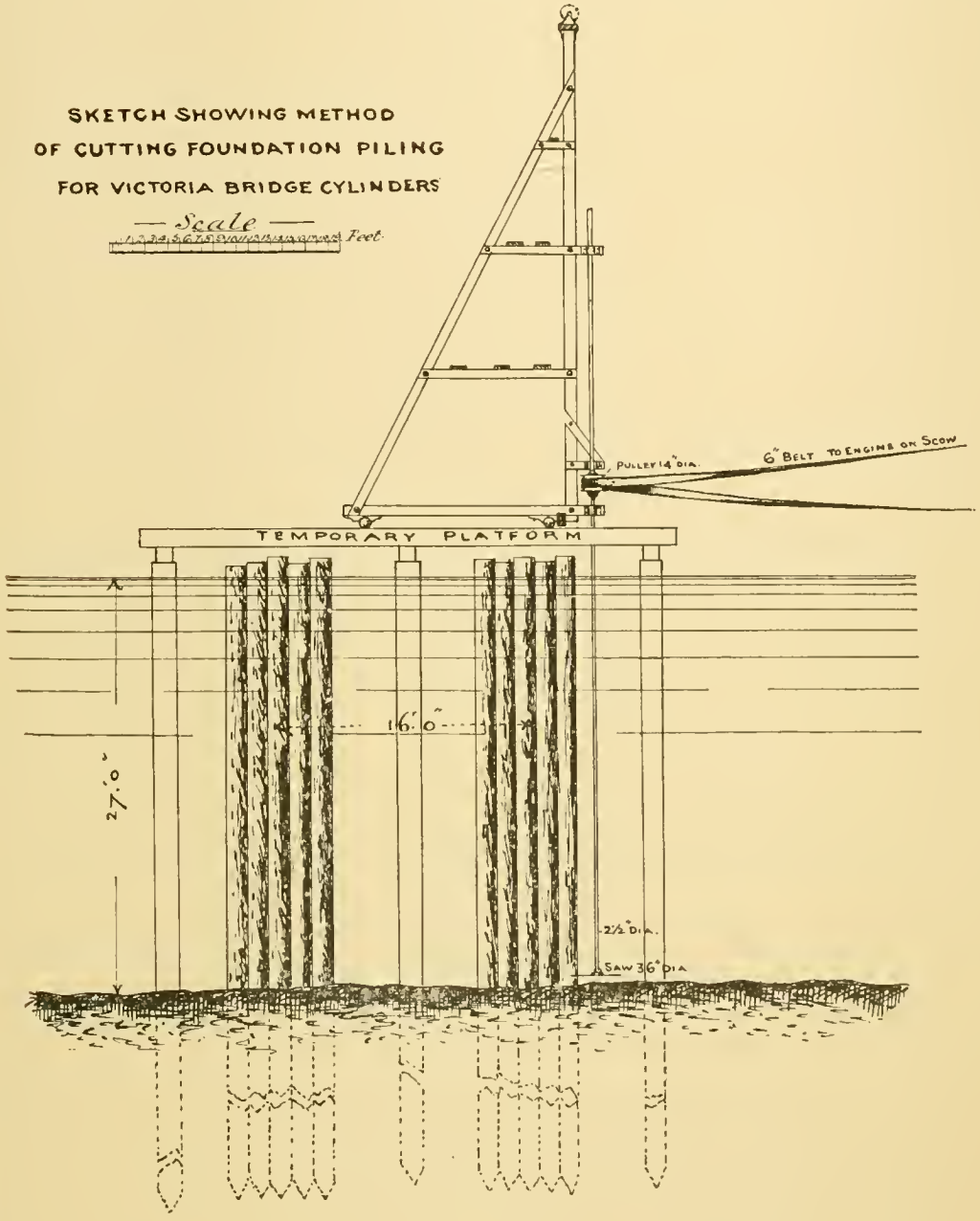


FOUNDATIONS RESTIGOUCHE BRIDGE, INTERCOLONIAL RY.

VOL XXIX, No. 625.
TRANS. AM. SOC. CIV. ENGRS.
MURPHY ON BRIDGE SUBSTRUCTURE IN NOVA SCOTIA.
PLATE X.

SKETCH SHOWING METHOD
OF CUTTING FOUNDATION PILING
FOR VICTORIA BRIDGE CYLINDERS

— Scale —
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Feet.



So regular is this periodical flood that it is annually anticipated. The spring freshet is distinct from the 'run of ice,' several weeks intervening. It always occurs immediately after the warm weather sets in and is due to the melting of the snow in the uplands, where the tributaries take their rise. This freshet usually raises the Metapedia 12 ft. and the Restigouche 18 ft. above ordinary summer level. The rise of the water is gradual, and still more so is its fall; the former generally occupies several days, and the latter as many weeks; the river rarely assuming its ordinary level until the last week in June."

"The Restigouche has been famous for its lumbering operations for half a century, and a great quantity of timber is still cut on its banks. The contingency of rafts and drift logs striking the piers and endangering the superstructure had to be provided against."

"Every precaution has been taken to render the piers of the bridge capable of resisting the formidable forces to which they will periodically be exposed. It is believed that they will remain uninjured."

"It has been stated that the masonry is built on a pile foundation, except in the easterly abutment, which is built on rock. Although, owing to the current, the ice impinges with great force on that side of the river, the foundation being well let into the rock, and the wall being well built and protected, no injury is likely to result."

"The masonry, generally, is built of stone found in the adjoining railway cutting, on the south-easterly bank, where blocks of good dimensions were obtained. The work is executed in courses, 30 ins. thick on the footings and 24 ins. in the body of the work, the blocks being from 6 to 8 ft. long."

"The stone is tough and well adapted for work requiring great strength. Being difficult to dress, however, except in the line of cleavage, it was decided to use granite for the cut-waters and quoins."

"The granite was brought from the River Nepissiguit, beyond Bathurst. It is not unlike the well-known Aberdeen granite, the scales of mica only being somewhat smaller."

"The distance from the quarry is nearly 90 miles, 70 of which only were by open navigation. The blocks were therefore prepared in the quarry, and, when reduced to their proper size, weighed from 3 to 9 tons each."

"The necessity for great strength is evident from the foregoing account of the phenomena yearly witnessed in the river, which no light structure could resist. The face stones of the cut-waters, the coping, bridge seats, and the two upper courses of ashlar, together with the skew quoins on the down-stream end of piers, are granite. A striking contrast is accordingly obtained to the dark slate color of the body of the masonry, which adds to the appearance of the structure."

"The total quantity of masonry exceeds 6 000 cu. yds.; the whole is built in Portland cement, and the exposed parts of piers were

secured by strong iron clamps, so contrived that it would be impossible for floating logs or ice to disturb a single stone without moving the whole mass to which it is attached. The work was commenced in the summer of 1870 and completed by Christmas, 1875. During the whole of that time, notwithstanding the heavy plant and material employed, not a single serious casualty occurred."

The foundations and substructure cost $276 000.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

626.

(Vol. XXIX.—September, 1893.)

IMPROVED METHOD OF CONSTRUCTING FOUNDATIONS UNDER WATER BY FORCING CEMENT INTO LOOSE SAND OR GRAVEL BY MEANS OF AIR PRESSURE.

By FR. NEUKIRCH, C. E., of Bremen, Germany.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

This improved method of constructing foundations has for its object to convert the sand or gravel, existing under water at the locality where the foundations are to be made, into a solid body in the form of sand or gravel concrete. This conversion is effected *in situ*, so that no excavation to the solid bottom is required. The sand is converted into sand concrete by forcing cement in the form of powder, as it occurs in commerce, through a pipe by air pressure into the submerged

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

sand. The pipe has an internal diameter of about $1\frac{1}{2}$ ins., and is drawn to a point at the lower end, in which there are three or more holes of about $\frac{3}{8}$ in. diameter. The upper end is connected by a bend and rubber tubing with the air-pressure supply pipe in such manner that the pipe can be raised, lowered and moved while the air pressure is flowing through it.

In the air-pressure supply pipe, provision is made by means of suitable branches and stop-cocks for connecting therewith an apparatus which by means of an injector device enables any desired quantity of cement powder to be fed into the air current. The air pressure, together with the cement powder, issues through the small openings at the lower end of the lance pipe, and is driven with considerable pressure into the sand foundation ; this is very mobile as it is entirely under water, and consequently the blowing in of the cement produces a motion in the foundation pit similar to that in a vessel of boiling water, the steam bubbles instead of air bubbles being formed. The cement carried by the air is retained by the wet sand and combines with this to form sand concrete.

By the boiling motion an intimate mixture of the wet sand with the cement is effected.

After the injection of air has ceased, the grains of sand in subsiding adhere very firmly together, and experiments have shown that a natural bed of sand, after having one-fifth of its volume of cement injected into it, will after the operation occupy a smaller space than before ; this was shown by the fact that the surface of the sand concrete lay deeper than that of the surrounding natural sand-bed.

The introduction of the lance tube into the sand-bed is effected by first blowing air through it, so that the air issuing from the lower end forces back the sand and in setting it in motion renders the sinking of the tube to considerable depths, such as 16 to 19 ft., readily possible in a comparatively short space of time; this operation is rather more difficult only when the bed is not purely sand, but contains larger stones, wood, etc. In this case it may be necessary to raise the tube up again and to insert it at a different place so as to avoid the obstructions.

In order to insure a uniform mixture in the foundation pit, it is divided into small fields of from 8 to 12 ins. square, and into each of these the required quantity of cement, which is ascertained by dividing the cubic contents of the field by the required proportion of the

admixture, is blown. The lance tube is first sunk in each field down the solid substratum by means of air pressure alone ; when it has attained this depth, cement is supplied to the air current, and during the continued introduction of the cement powder the tube is slowly drawn upwards until the required quantity of cement has been introduced.

In order to enable the lance tube to be readily handled, it is suspended from a tripod or traveling stage having a small winch by means of which the tube can be readily raised and lowered. The movable stage has the advantage that it enables every field of the foundation pit to be easily reached. The steam-boiler and compressor for producing the air pressure can be placed at a greater distance from the foundation pit ; the air pressure can readily be conducted through wrought-iron pipes to the point required. It is of advantage to warm the air in the vicinity of the cement apparatus, as otherwise moisture might be separated by the cooling of the air, which would be very inconvenient in working and easily produce a clogging of the cocks and injector nozzles.

For warming the air a small cast-iron stove is employed, consisting of two cylinders inserted one within the other and connected together air-tight. In the inner cylinder is a fire grate on which a light fire is maintained. The air pressure is made to circulate through the annular space between the two cylinders. The inner cylinder has external ribs formed on it, so that the air pressure is brought in contact with a considerable heating surface on its way through.

The steam-boiler and compressor can be arranged as a portable engine, so as to enable the apparatus to be readily transported from one foundation pit to another.

This method of constructing foundations may be compared with the ordinary method of making concrete foundations, in a similar manner as the Bessemer process compares with the puddling process in the manufacture of iron. In the Bessemer process the blowing of air into the molten pig iron causes the carbon to be burned and a solid metal steel is produced, while in the puddling process this conversion is effected only by laborious stirring. In the new process of making foundations the blowing of the cement into the stratum of liquid sand, as it were, converts it into a solid body, while up to the present time this was also only effected by laborious stirring.

As the entire process is mainly carried out by machinery and requires only a small amount of manual labor, foundations can be carried on rapidly by this process.

If it be desired to transmit the pressure which the foundations have to bear to a substratum below that upon which the sand-bed lies, this can be effected by driving in piles to the required depth before the cementing process is commenced. These piles will then be completely imbedded in the sand concrete and be firmly united therewith, so that they may be considered as part of the structure.

If it be desired to sharply limit the lateral dimensions of the body of sand concrete, or to protect it against external influences, the foundation pit is in the first instance surrounded by a coffer-dam.

The hardening of the sand concrete formed as above described takes several weeks, and the complete hardening, several months, as in the case of ordinary concrete under water.

On the accompanying drawing (Plate I) is shown the necessary plant for carrying out the above-described process, as also the application thereof for some cases.

Fig. 1*a* shows the arrangement of the steam-boiler, compressor, air reservoir and heating stove for the air-pressure supply, which should always be situated near the place of operation. Fig. 1 shows the application of the process for consolidating the soil round a brick sewer so as to insure its being water-tight against the surrounding aqueous sand stratum, and to afford it a rigid bed therein.

The sewer, which is 5 ft. internal height, lies in quicksand, and had become so leaky that the sand penetrated into it in considerable quantity. Owing to this, the road pavement and also the neighboring houses subsided, so that it became urgently necessary to provide a remedy. This could not readily be done in the usual manner, as it appeared very hazardous to drive coffer-dams in the somewhat narrow street. By applying the above-described invention the sewer was made perfectly tight and secure for a length of about 500 ft.

Fig. 2 shows an application of the process in the harbor of Vegesack near Bremen. For the quay wall a bulkhead of rolled iron was used. Wood could not be used for this purpose, because the bed is very stony, and because in consequence of the ebb and flood the dam is not always altogether under water. Such iron dams are with diffi-

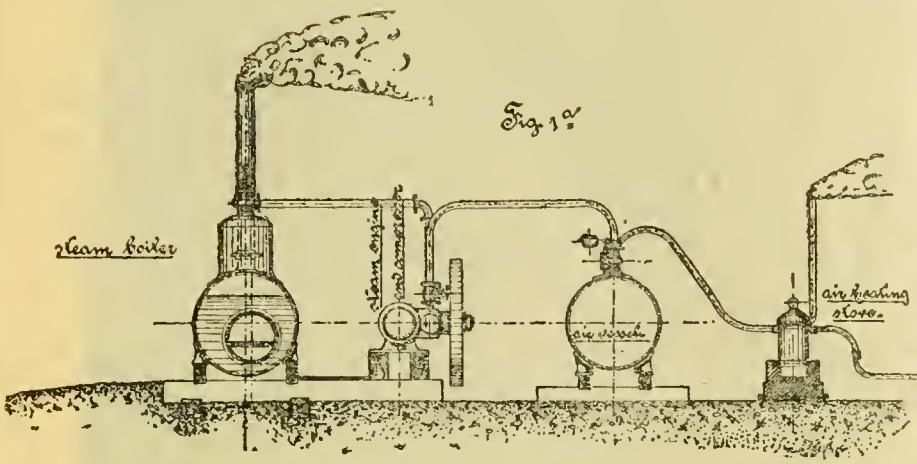
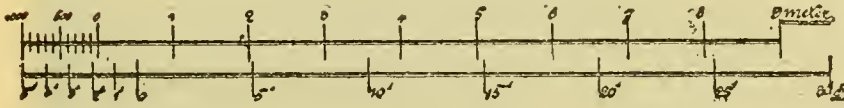


Fig. 1a.



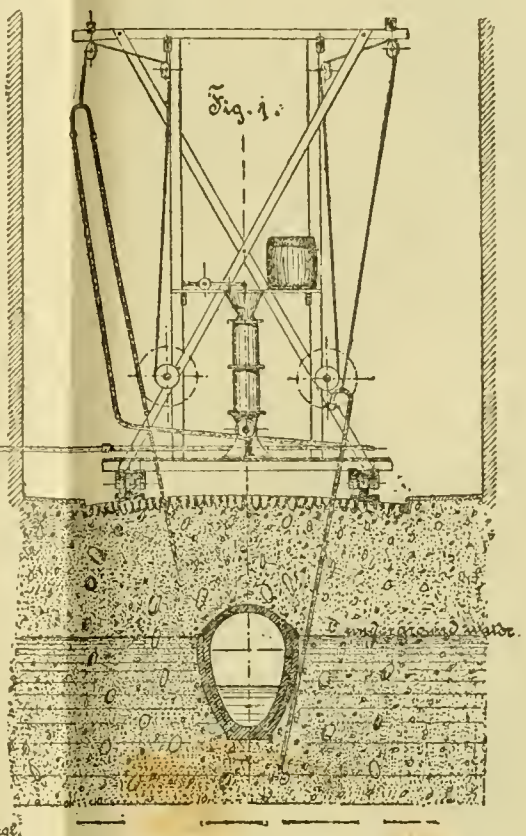


Fig. 1.

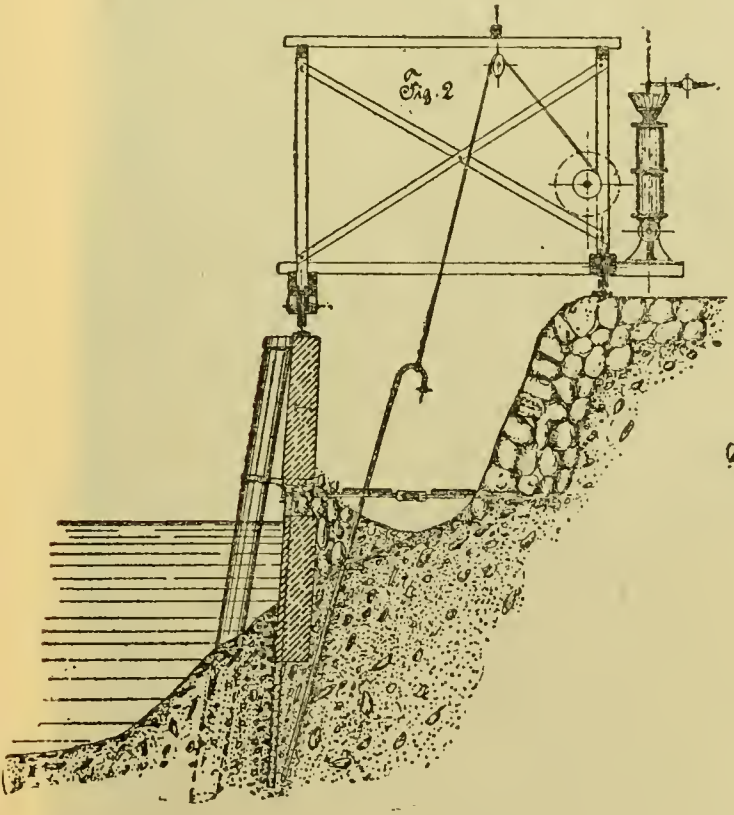


Fig. 2.

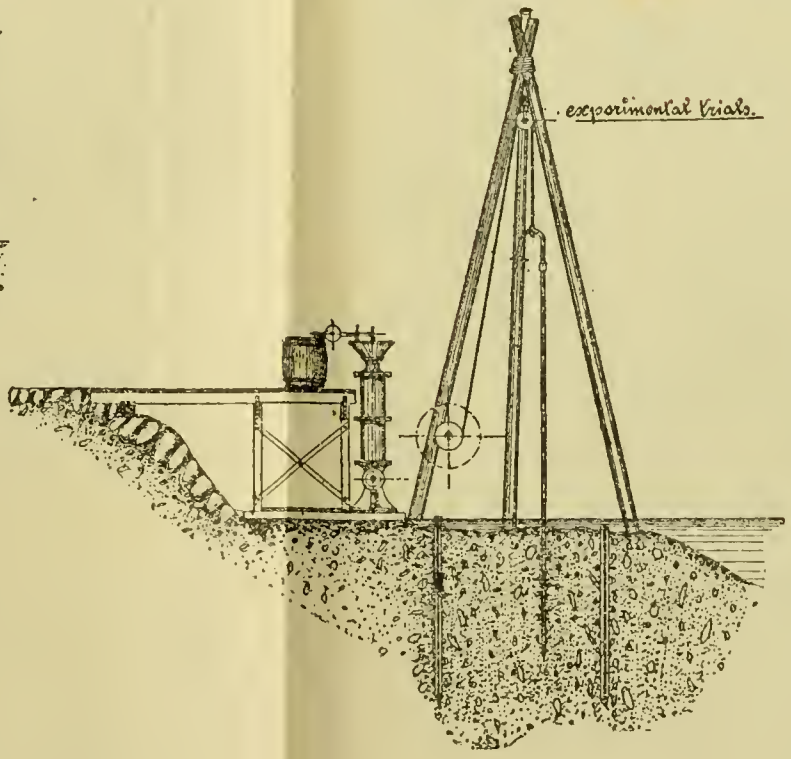


Fig. 2a.

requ
carr
I
have
bed
dep
will
unit
stru
I
of s
foui
T
take
the
C
plan
cati
F
rese
alwa
plica
so as
sand
T
beco
Owi
subs
This
very
appl
tight
F
sack
used
very
is no

culty made completely tight. By blowing in cement behind the dam, it was rendered perfectly tight and safe.

Fig. 3 shows the arrangement employed for experiments.

A simple tripod is in this case erected for suspending the lance tube, while in the previously described arrangements a movable frame was employed.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

627.

(Vol. XXIX.—September, 1893.)

AMERICAN GRAIN ELEVATORS.

By E. LEE HEIDENREICH, Member of Scandinavian Eng. Society of Chicago; Am. Inst. Min. Engrs.; Western Society of Engrs.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The handling of cereals on a vast continent naturally becomes a problem of, not only national, but universal prominence, and ever since the forties it has been considered one of the principal problems encountered by the commercial element of the United States. Realizing the importance of making a *résumé* of the progress of construction of American grain elevators as short and concise as possible, owing to the large number of papers to be brought before this distinguished assembly, the writer will confine himself to a description of modern elevators merely, without touching upon the history of grain handling in America any more than is absolutely necessary.

The *modus operandi* of a grain elevator is about as follows:

1. A power car-puller sets a string of cars each opposite an elevator leg, or vertical grain conveyor, located about a car-length apart.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

2. Car-doors are opened, two shovelers enter each car and handle each a shovel operated by rope from a power-shovel shaft in the elevator.

3. The grain drops into a receiving hopper, is elevated in buckets bolted to a rubber belt 150 ft. to the top floor of a cupola, where it is discharged, in turning over a head pulley, into an accumulator, or garner, and thence into a weighing scale.

4. From the scale the grain is spouted;

a. On conveyor belts running horizontally and discharging over movable trippers into storage bins. (Storage elevators.)

b. In car spouts for reloading or transferring. (Railroad transfer elevators.)

c. Directly into storage bins.

Into shipping bins with dock spouts, to be loaded into vessels.

Into car spouts. (Terminal elevators for rapid handling and storage.)

d. Into garners above cleaning machinery. (Cleaning elevator.)

5. When the cars are empty the shovelers take with them the power-shovels across the working floor (about 14 ft.) to a string of cars set in on the opposite side of the elevator, where the performance is repeated, while the first string of empty is being replaced by loaded cars.

In addition to the four classes of elevators mentioned we have the marine elevators, receiving grain in bulk from vessels—usually by means of one stationary and one movable marine leg—so as to unload two hatches simultaneously. The grain is elevated into a garner, weighed and re-elevated, or spouted, on conveyors into storage, or transferred into cars.

The sixth class of elevators are the small country houses, or railroad station elevators, where grain is weighed in farmers' wagons and dumped into a pit, elevated, stored, and for shipment re-elevated, weighed in a hopper scale and spouted into a car. The accompanying plates explain themselves, and, as there is nothing that can interest an engineer in their construction, no further reference will be made to them.

The Construction of Storage Elevators.—The want of additional storage at a railroad terminal is usually dictated by immediate demand, and for this reason this class of elevators is constructed usually with greater attention to cheapness and rapid completion, combined with

strength, than to mechanical details. There have been cases where the problem has been put to an elevator builder in this way: "We want 3 000 000 bushels of storage, with a handling capacity of 200,000 bushels per day, constructed complete within 45 days; can you do it? and at what price? If the builder says, "Yes; I can do it at 5 cents per bushel," the contract is signed and operations commenced at once. An excavation is made about 18 ins. deep, if in clay or sand, and the same covered with hewn railroad ties in such manner as to get the entire surface as a basis for the superimposed load. Three or four timbers are laid side by side in bents from 11 to 14 ft. apart across the ground, and from 12 to 50 ft. longitudinally. Short cross corbels are rested thereon, supporting cross and longitudinal timbers, upon which the cribbing is spiked. The cribbing consists of pieces of 2 x 8 or 2 x 6 common pine or hemlock, usually surfaced one side and one edge, laid flat on the top of each other, and spiked with 30d spikes every 12 ins., zig-zag. The two first cross bents of the elevator are usually built on posts, so as to form a working floor from 20 to 28 ft. wide across the width of the elevator. Here are located the elevator legs, or vertical grain conveyors, at a distance of from 36 to 40 ft. from center to center, according to the length of the freight cars. These legs extend into the ground about 12 ft. from the working floor, so as to be able to take grain from a receiving hopper, extending to a point between the rails of a track running alongside the front of the elevator as close as the cars will permit. The angle of the receiving hopper with the horizontal is in the neighborhood of 35°, or 2 to 3, so that the corners of the receiving hoppers will clean themselves of oats. The height of the planking, in the rear or storage part, varies considerably according to the value of the building site, and runs from 40 to 85 ft. in height. Above the planking, *i. e.*, above the bin floor, a so-called cupola is erected directly over the space before designated as a working floor. In this cupola a series of scales for weighing the grain received or shipped is located, and inasmuch as, particularly in shipping, the elevator legs receive grain all the time, it is usual to locate, immediately beneath the discharge spouts of the elevator legs, a garner or accumulator above each scale for the purpose of receiving the grain while the scales are weighing and unloading. Another system of somewhat older date is to use two scales, called twin scales, for each elevator, accomplishing the same purpose. On the bin floor immediately

beneath the scales and extending longitudinally with the elevator, is a series of grain conveyors, consisting simply of endless belts varying in width from 16 to 40 ins., on the upper line of which is located a so-called tripper, which is movable on a track running from one end of the elevator to the other. In receiving grain it is spouted down on said conveyors, and the tripper is located above the bin or reservoir in which the grain is to be stored. The speed of these belts in modern elevators is about 700 to 800 ft. per minute, and, although the surface of the belt is perfectly flat, the cohesion between the kernels of grain is such as to gather the grain towards the center of the belt in such manner that from 2 000 to 20 000 bushels per hour can be conveyed. The bin bottoms in a storage elevator of this kind are usually flat, consisting of 3 x 14 joists, placed about 9 in. on centers, and covered with 2 x 6 dressed and matched flooring. Sometimes this floor is laid directly on the ties on sills, but this practice is not to be recommended, as it leaves less chance for ventilation. For unloading the grain from the elevator, belt conveyors are located along the bin bottoms at convenient distances so as to reach the front receiving or shipping legs, and are covered with planking or cribbing, or planking on the sides with timbers overhead, in such manner as to form tunnels, extending from the working floor to the end of the elevator.

In receiving grain from the cars, a train consisting of as many cars as there are receiving legs is detached by means of a power car-puller from a string of from 20 to 30 cars set in by a switch engine. Owing to the different lengths of the cars, they are detached and "spotted" or located each opposite a receiving leg. The exterior covering of a storage elevator is usually of corrugated iron, with a tin or aluminum alloy roof.

Inasmuch as the elevator legs must extend some 8 or 10 ft. into the ground, they are located in steel tanks of $\frac{1}{4}$ to $\frac{5}{16}$ material, and, to prevent the collapse of these by the pressure from the superstructure, it is a good practice to drive a few piles on each side of each tank and cap them with timber in such a manner as to bridge the tanks.

As for time, the principal item in rapid construction of this kind is to get the material on the ground. The planking or cribbing can be done at the rate of 6 to 7 ft. a day, so the main structure, from the top of foundation to the bin floor, can be finished in 12 to 15 working days, when properly managed.

Where the bins or grain reservoirs are more than 12 x 16 ft. area, they should be rodded. A good rule for calculating the rodding of a bin is to imagine a bin filled with grain, turned over flat and the side suspended by rods running through the grain. As the rods should not exceed ⅜ in. or ½ in. diameter steel, it gives a space between the rods in large bins of about 5 ft. square. Formerly the practice was to increase the diameter of the rods towards the bottom of the bin, but it has been proved that the horizontal pressure in a bin is practically constant from within 15 ft. of the top to the bottom. The reason for this is that grain such as corn, wheat and oats in bulk forms a peculiar bridging, leaving the pressure on the bottom, under ordinary circumstances, constant for any height above twice the width of the bin.

Experiments have given the load on an equilateral bin bottom as very nearly equal to the weight of a paraboloid of a height 1.8 times its base, and this fact led the writer to make the bin rods the same diameter from bottom to top of bin, with good results.

In some of the older elevators where the bin rods at the bottom were from 1½ to 2 ins. diameter, it has been found that the down draft of the grain in unloading the bin bent the rods and pulled the washers into the bin walls, while the ⅝ to ⅞ in. rod seems to cut through this suction without damage. But for this peculiarity of grain, the construction of bin bottoms would present great difficulties, the static load figuring up to 4 000 lbs. per square feet.

Railroad Transfer Elevators.—The second class of elevators are the railroad transfer elevators. Some State legislatures have during the past few years passed acts compelling railroads to give hopper scale weights on transferred grain, and as a result a number of transfer houses have been built, handling from 100 to 300 cars per day. Their construction presents few difficulties, as they have no storage capacity whatever.

Two tracks run entirely through the building, the elevator machinery being placed in the platform space between the tracks. The cupola, with the elevator heads and scales, is located directly above the first floor, at a height to give sufficient fall, through car spouts, to trim or fill the cars without the use of manual labor in the cars.

Terminal Elevators.—The third class of elevators refers to terminal houses for storage, rapid handling and shipping, either by lake and rail or both. In general, these houses are termed "up houses," *i. e.*, they are entirely built on posts, in such manner as to form a large working floor

beneath the entire storage area. From three to four railroad tracks are run through the entire length of the house, and, according to the number of cars the house can unload simultaneously, they are termed 5-car, 8-car, 10-car houses, etc. The most modern construction locates all receiving and shipping elevators in one line, with receiving tracks on each side, thus occupying the three center bents of the elevator. The loading tracks are usually located in the outside bents, while, of course, the center tracks are arranged for shipping purposes. Owing to the size of the car, the transverse bents in the house are at least 13 to 14 ft. each, which makes the house either 56, 70, 84 or 98 ft. wide. Longitudinally the bents usually are in succession, 12, 12 and 14 ft., leaving the elevator legs at a distance of 38 ft. from centers. At the end of the elevator the power-house is located, in such manner that one of the loading tracks passing through the house also passes the engine-house, so that coal may be received from one end while grain is loaded into cars going in an opposite direction. All bin bottoms in a house of this description are hopper bottoms, and all bin openings of a diameter sufficient to fill elevator legs or conveyors to their full capacity.

A modern rapid-working terminal elevator is equipped with the very best machinery, electric lights, fire pump and service, passenger elevator, dust collectors and floor sweepers—in short, all contrivances that will cheapen or lessen labor and promote rapid handling of the grain. As the entire building rests on posts, the loads are concentrated at certain points. The load per pier varies from 300 to 450 tons, and as the safe bearing capacity of the soil seldom exceeds 2½ to 3 tons, piling is resorted to, with cross and longitudinal oak grillage and stone piers. As the entire load of grain is thrown on the bin walls, the girders supporting these walls between the clusters of posts must be of a very strong construction, usually two 12 × 14 long-leaf yellow pine or oak sticks, on top of each other, supported by white oak corbels braced back into the posts below. Formerly the entire basement was taken up by stone piers and elevator tanks, but the tendency is now towards using less stone and extending the posts into the basement, leaving it open and concreted smoothly, so as to enable the removal of the dust and the admission of light below the first floor. Fireproof construction of the first floor and basement is much to be recommended, although it materially increases the cost of the elevator.

Cleaning Elevators.—Under the head of cleaning elevators we encounter the most complicated construction and the greatest variety of details. The writer will, however, confine himself to what has been adjudged the most improved arrangement.

The receiving department of a first-class cleaning elevator is practically that of an up-house or handling house, as may be seen by referring to the accompanying sketch. Between the first and bin floors is, however, inserted a cleaning floor, a separate department with garners above and garners beneath. In this manner the grain from the scales is spouted into the garners; thence, by gravity, through the cleaners into the lower bins, whence it is elevated and spouted into storage, shipping bins or car spouts. By enabling a number of small bins overhead and below the cleaning floor to communicate with the cleaners, it can readily be seen that any mixing or grading can be done without difficulty.

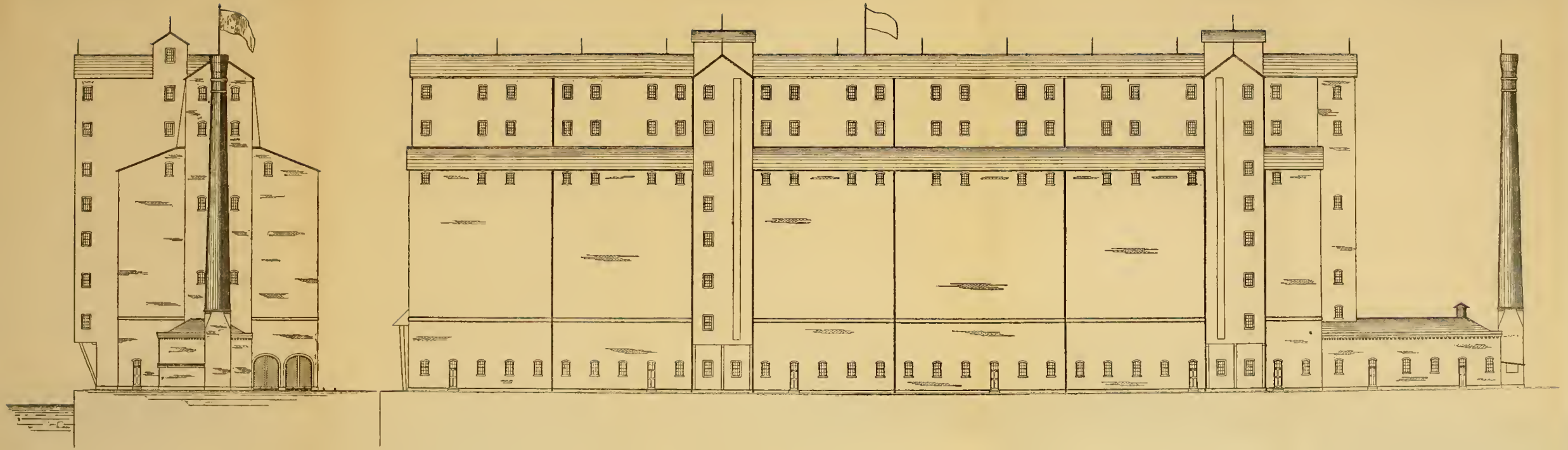
If cleaners are located on first floor or bin floor, elevator legs are required for either taking away from or supplying the cleaners, and as the capacity of a leg is 5,000 to 6,000 bushels per hour, while a cleaner only averages 2,000 and an oat-clipper 500 bushels, it is clear that there is a waste of machinery in this arrangement.

The dust from the cleaning machinery is blown into separators or cyclones, and exhausted by a powerful fan and blown into a large separator located directly above the boiler furnaces, where the dust and chaff form a material part of the fuel. The floor-sweepers before alluded to consist of 6-in. suction pipes extending to the floor, where a nozzle is attached, flat flared out, with a sliding gate. Any sweepings are brought in the vicinity of the nozzle, the gate is pulled out, and the sweepings are, a few seconds later, consumed in the boiler furnace.

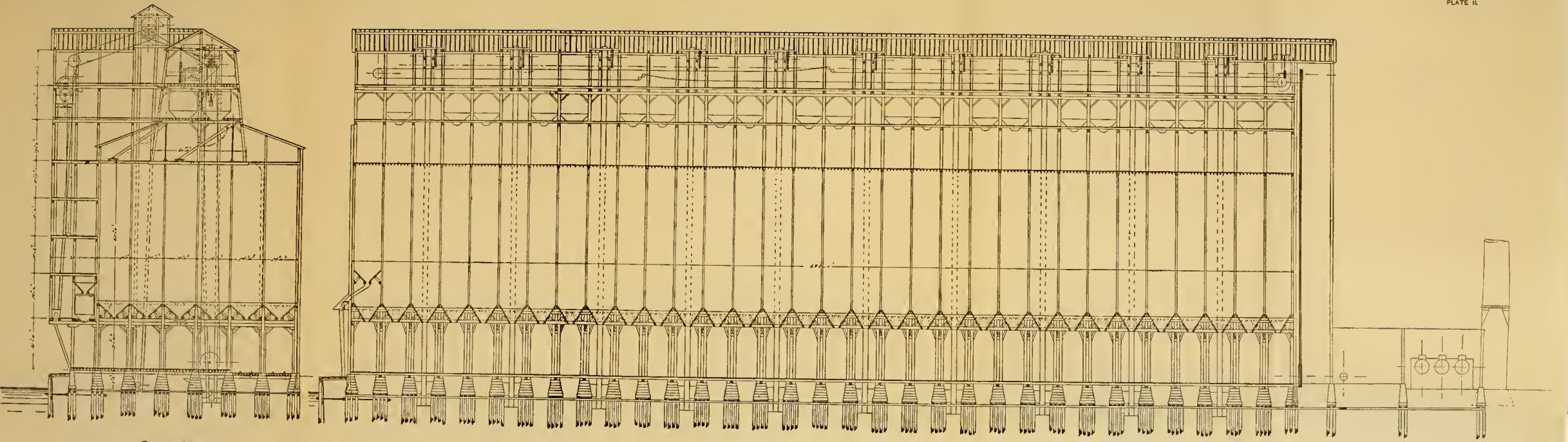
In a similar manner the dust from the elevator heads, garners and hoppers is disposed of. The surplus air from the fans in the cleaning machinery is thrown into a couple of large air conduits discharging above the cupola roof.

The storage of a cleaning elevator of this description consists of an annex, loaded and unloaded by means of belt conveyors. The annex should have hopper bottoms, and is shown in the accompanying plate built on ties, while the front or cleaning part is built on piles. Owing to a certain shrinkage in the planking, or cribbing, many difficulties are often met where an up-house joins a low annex, as while

VOL. XXIX, No. 627.
TRANS. AM. SOC. CIV. ENGRS.
HEIDENREICH ON AMERICAN GRAIN ELEVATORS.
PLATE I.



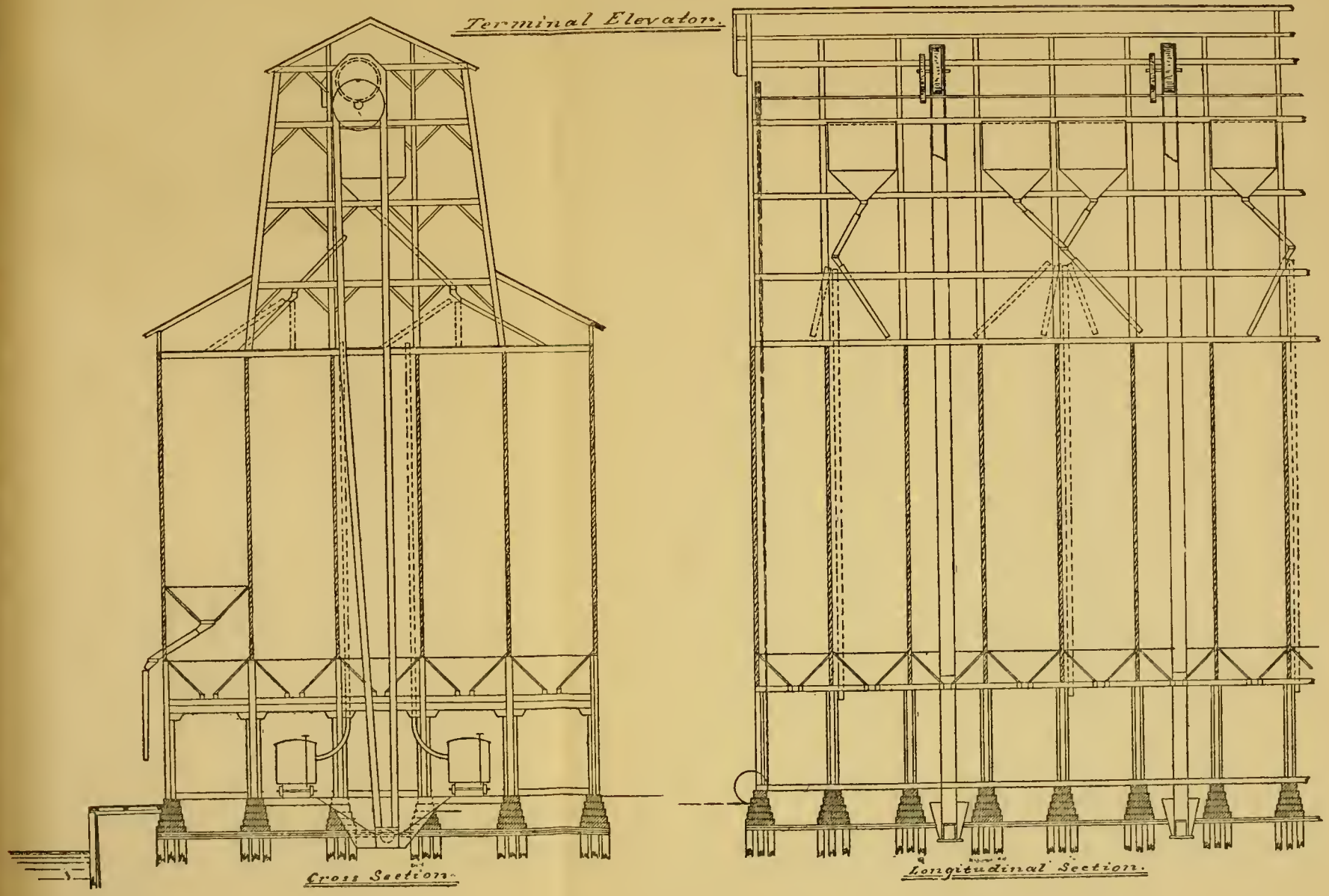
VOL. XXIX, No. 627.
TRANS. AM. SOC. CIV. ENGRS.
HEIDENREICH ON AMERICAN GRAIN ELEVATORS.
PLATE II.



Cross Section.

Longitudinal Section.

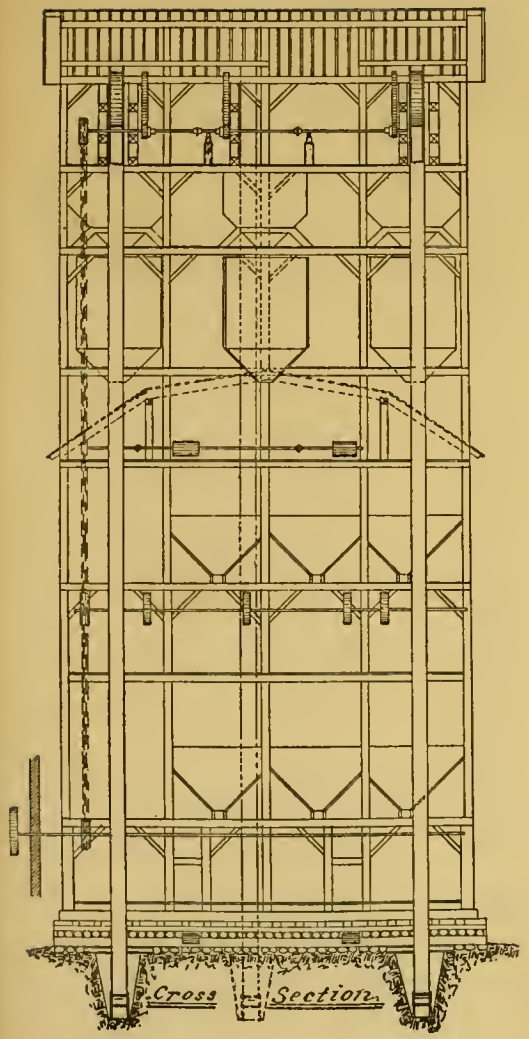
Terminal Elevator.



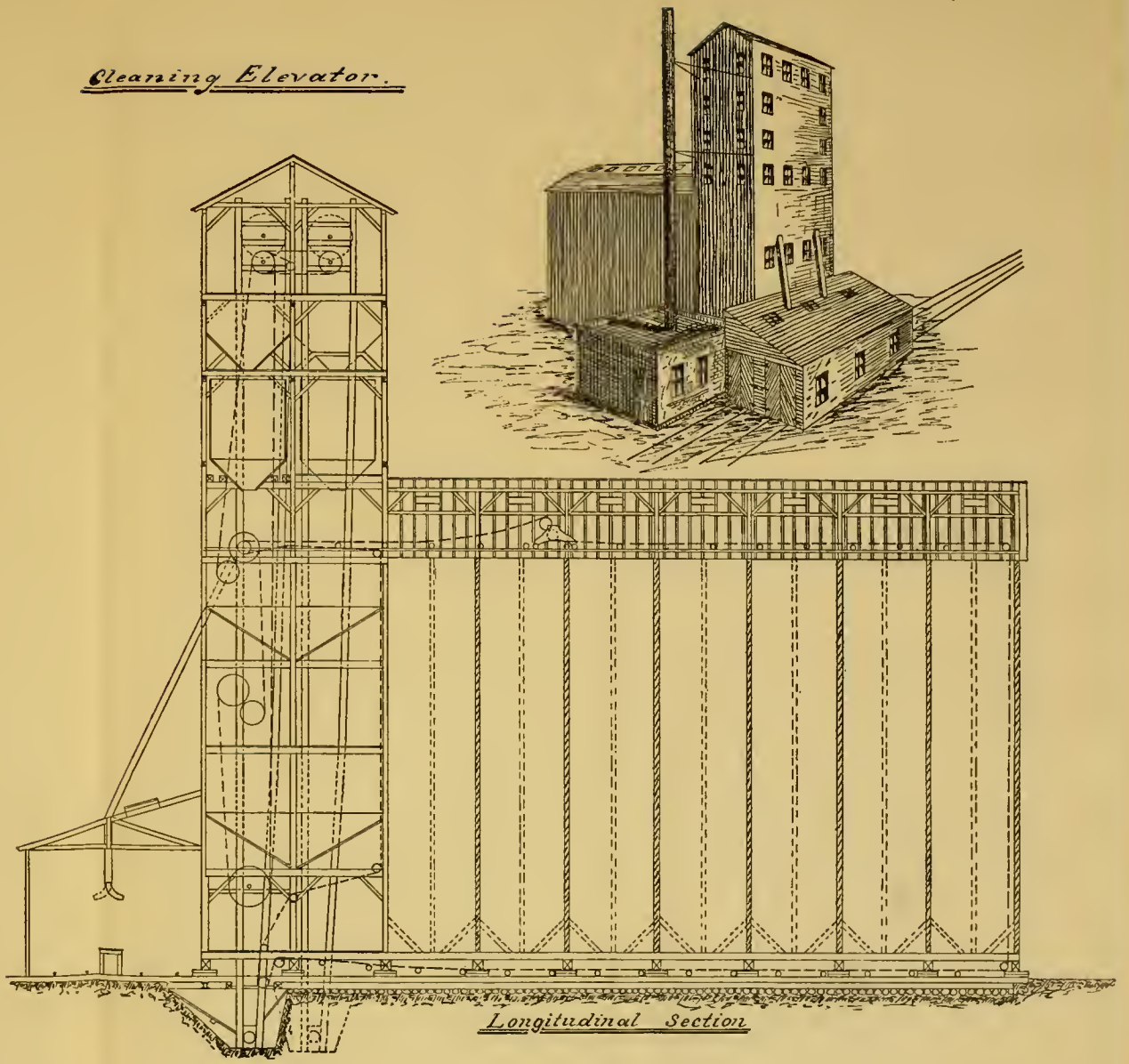
Cross Section.

Longitudinal Section.

Cleaning Elevator.



Cross Section.



Longitudinal Section

the posts in the former retain their length, the planking in the low annex shrinks several inches in the same height. This is usually remedied by giving the cross timbers running into the annex a corresponding camber, so that when the house has settled it will be nearly level.

Some builders erect the entire cupola of any elevator on independent posts extending through the bins, to counteract any influence of the shrinkage on the driving machinery, but the writer's experience is that the cribbing shrinks so evenly that no material trouble occurs on this score, so that he considers it advisable to build the cupola directly on the cribbing.

As to the driving machinery in grain elevators, it has changed materially during the past six or eight years. The most approved method to-day is a high-speed engine with manilla rope transmission from the engine to the last piece of machinery in the elevator. In a cleaning house the cleaner shaft should run about 250 revolutions per minute, as the cleaning machinery runs at a speed from 400 to 550 revolutions per minute, and the engine from 100 to 150 revolutions per minute. A direct rope transmission from a main-line shaft in the cupola to each of the elevator head pulleys is found to give satisfaction. The usual practice is to have eight strands of 1-in. rope for each transmission, the rope speed being only about 750 ft. per minute. It is very important that all the machinery in an elevator be strictly first class in every respect, as any hitch or slip in the driving gear is sure to cause serious chokings of the grain where it enters the elevator leg.

Grain elevators are usually covered with either brick or iron; in case of brick the unevenness in the settling between the exterior brick shell and the main structure is taken care of by means of anchors with slip joints, permitting the planking to go down 12 to 24 ins. without disturbing the tie between both parts. In case of corrugated iron covering, the sheets are put on with corrugations running vertically, and nailed 4 ins. from the lower edge only, so that the shrinkage of the planking is taken care of separately for each sheet.

The best roofs are probably the I. C. old process charcoal tin, although last year a large cleaning elevator was built with a roof of aluminum alloy metal, greatly reducing the weight and having the advantage of not requiring painting.

The principal requirements of a grain elevator, namely, strength, tightness, light, and effective and accessible machinery, are such as to invite the attention of engineers; and before closing the writer wishes to say that the handling and storing of grain, both in the Interior and at the lake and ocean terminals, presents a wide field for future discovery and improvements. Some of the immediate wants are: larger capacity cleaning machinery, adequate drying apparatus, automatic weighing machinery, fireproof bin construction, and pneumatic unloading of cars or vessels with a view of greater capacity per hour than can be obtained at present. And last, but not least, a general use of electricity for driving isolated parts of machinery, or, perhaps, for transmitting power to every piece of machinery in the entire elevator.

The main principles which must be kept in view while making these improvements are rapidity and economy of construction, and a reduction of the labor employed in the handling of grain in American grain elevators of the future.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

628.

(Vol. XXIX.—September, 1893.)

THE MANUFACTURE AND USE OF PAVING BRICK.

By DANIEL W. MEAD, Mem. Western Soc. Engrs., Assoc. M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The generic term brick includes within its meaning classes of material of such wide variations in their particular qualities as to need a more definite classification when considering the adaptability of such classes to particular purposes. Not all brick are qualified to withstand the high heat of the blast furnace which firebrick so well resist; neither are all brick suitable for the decorative work so well performed by enameled and pressed brick. So, when we consider a certain class of this material for street paving, it must not be confused with other classes manufactured for other purposes and perhaps entirely unfit for this particular use.

These manifold qualities of brick are due partially to methods of manufacture, but more largely to greatly diversified qualities of the clay from which the brick are made.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Occurrence and Distribution of Clays.—Clays may be classed as to their origin and occurrence as follows:

I.—Residuary clays result from the disintegration of rocks in place. The soluble and binding materials are leached out and washed away and leave the insoluble materials in a more or less divided form, as clay. This takes its character from the character of the rock from which it is derived, modified by the action of water. Some of the purest clays are derived in this way from feldspathic rocks from which the alkalies have been leached, leaving a clay closely resembling kaolin (pure clay). Other less pure clays are derived from the disintegration of limestone, sandstone, etc.; in each case, however, the soluble constituents are almost entirely gone, leaving the insoluble silicates, quartz grains, alumina and ferric oxide. Clays Nos. 1, 2 and 3 in Table No. 1 are examples of this class of clays.

TABLE No. 1.

	Residuary Clays.			Drift Clays.	
	From Limestone.		From Granite.		
	1.	2.	3.	4.	5.
SiO_2	71.13	49.59	78.83	40.22	48.81
Al_2O_3	12.50	18.64	13.43	8.47	7.54
Fe_2O_3	5.52	17.19	.74	2.83	2.53
FeO	.45	.27	....	.48	.65
TiO_2	.45	.28	....	.35	.45
P_2O_5	.02	.03	....	.05	.13
MnO	.04	.01	....	trace	.03
CaO	.85	.93	.64	15.65	11.83
MgO	.38	.73	.07	7.80	7.05
Na_2O	2.19	.80	.07	.84	.92
K_2O	1.69	.93	.37	2.36	2 60
H_2O	4.63	10.46	5.45	1.95	2.03
CO_2	.43	.30	....	18.76	15.47
C	.19	.34	....	.32	.38
SO_3	....	....	. ..	.13	.05

Nos. 1 and 2 are from the same vertical section, No. 1 being 4½ ft. from the surface, and No. 2, 8½ ft. from the surface and in contact with the underlying limestone. (Report of Director U. S. G. S., Vol. 6, p. 250. No. 3, see Wis. Geo. Survey, Vol. 2, p. 476.)

II.—Drift clays are the result of the mechanical action of the ice during the Glacial period, by which the various formations were ground up and mechanically transported and redeposited largely without the aid of water. These clays represent the character of the mother-rock much more accurately than those of Class I, as in this case the soluble matter is largely retained and not leached out, except by the action of the water, since their deposition. Of this class

Nos. 4 and 5 of Table No. 1 are drift clays from Milwaukee, Wis. (see U. S. G. S., 6th Annual Report, p. 280).

III.—Alluvial clays are residuary and drift clays rewrought and redeposited by fluvial agencies.

IV.—Indurated clays, or argilaceous rocks and shales, are formations resulting from the disintegration of the earlier rocks by various influences and their reformation into new strata. They have usually been subjected to great pressure from the superincumbent rocks, to which pressure they owe their physical character to a large extent.

Of these three classes, the residuary clays (Class I) are found wherever rocks and the result of their disintegration have been undisturbed by fluvial or drift influences, and are hence found largely outside the drift areas. The clays of Class II are found within the drift sheet and constitute the common brick clays of the Northern States (see Plate I). Those of Class III occur along the various river courses; while those of Class IV occur in the many geological horizons, which we may briefly summarize as follows, beginning with the oldest and lowest geological horizon. The clays occur in the Potsdam strata as shales interbedded with the sandstones.

In the Utica slate (sometimes considered the lower member of the Hudson River formation) as a dark carbonaceous clay slate, hard in Pennsylvania, soft in New York, sometimes interbedded with impure limestone.

In the Hudson River shale as shales and slates more or less interbedded with limestone (over 5 000 ft. thick in Pennsylvania and 200 ft. thick in Illinois).

In the Salina (or Onondaga salt group) as a red shale (in New York State, from 1 to 500 ft. thick).

In the Devonian as the Marcellus shales, a black slate, somewhat bituminous. As the Hamilton group, consisting of slates, shales and sandstones, 300 to 700 ft. thick; as the Genesee formation, the black slate of the West and South; as the Portage group, consisting of shales and flagstones; as the Chemung group, consisting of thin bedded shales, sandstones and flagstone.

In the Carboniferous, in which are developed the most extensive beds of fire clays, potters' clays, shales, soapstone, etc., interbedded with sandstone, limestone and coal (see map).

In the Triassic, which usually consists of dark sandstones, soft shales, and coarse conglomerates.

In the Cretaceous and Tertiary, which consists of earthy formations of sand and clays.

Of the deposits of clay above named, the clays from the Carboniferous period are most widely utilized for the manufacture of paving brick. At Columbus, O., the Devonian shales, or the product of their disintegration, is utilized, while at Syracuse the Salina shale is found available. Some few drift clays are also successfully used for the manufacture of a fair quality of paving brick, notably at Decatur, Jacksonville and Urbana in Illinois. A mixture of drift clay and carboniferous clay is utilized at Brazil, Ind., for the manufacture of paving brick.

The accompanying map shows the distribution of the carboniferous deposits east of the Rocky Mountains and also the outline of the drift area. It also shows the location of the principal paving brick factories and the principal cities which are now using this material for paving within the territory shown.

Character of Clay.—As may be judged from its wide occurrence and manifold compositions, clay varies widely in its extreme characters. But all materials to be classed as clays must have certain constituents in common. The essential ingredient is a hydrous silicate of alumina, known as kaolin, which, according to Professor G. H. Cook (see report on the Clay Deposits of New Jersey, 1878) is composed of—

Silica	46.3
Alumina	39.8
Water	13.9
	100.00

This may be considered a pure clay, and is rarely, if ever, found in Nature. To this is commonly added in varying quantities, silica, lime, magnesia, ferric oxide, potash and soda. The presence of these substances, which may be regarded as the impurities of clay, and the physical condition under which they exist, cause the wide variation in the clays themselves and to a great extent in the manufactured product made therefrom. There are also many other foreign constituents which are occasionally found in clays, but the above enter more largely and modify more widely the material as commonly obtained and utilized.

Character Due to Chemical Constitution.—Pure alumina will resist the highest temperature of the blast furnace, in which crystalline quartz

(silica) will be only slightly affected, both being practically infusible. Alumina shrinks, warps and cracks greatly in drying, but gives plasticity and adhesiveness to the clay and strength to the product. Silica prevents cracking and distorting, the more silica being present the less the shrinkage. But the more silica the less plasticity and adhesiveness of the clay and the less strength and greater brittleness. Lime and magnesia, while infusible in themselves or with alumina, fuse in the presence of an excess of silica, as do also several other common ingredients of clay, and form a "vitrified brick."

It is found that potash has the most active fluxing effect on clay, after which follows soda, lime, magnesia and iron, in the order named. To "vitrify," a clay should contain at least 3% potash, or 3½% of soda, or 5% of lime or magnesia, or 8% iron, or a combined proportion of any or all of these fluxes equal to these amounts. An appreciable less amount of these fluxing elements will leave the product more of the nature of a firebrick, unvitrified and porous, and, as a rule, unfit for paving purposes. A greater proportion than above specified is desirable, and will make the clay more easily vitrified at a less heat, and is to some extent a measure of its economic manufacture, as a lower heat and consequently less fuel will be required in its burning. Too great an amount of these fluxes, amounting, perhaps to three times the quantities above mentioned, will render the clay hard to handle on account of great fusibility. According to Richter, lime and magnesia are more active fluxing agents than potash and soda, but his conclusions do not agree with American experience. The presence of lime or magnesia in a paving brick in reasonable quantities is not believed by the writer to be detrimental to the brick if it exists in a finely divided state and is intimately commingled with the other constituents, so that a silicate of lime or magnesia will be formed in the burning. The Milwaukee building brick is one of the best of common brick, and it contains a large percentage of lime (see analysis Milwaukee clays, Tables Nos. 1 and 2), and Portland cement contains often as high as 60% of lime. In each case, however, the lime exists in close chemical or physical union with the other elements of the material.

Iron in considerable quantities has a fluxing effect with silica and to this extent cements it together and gives it strength. It is not the most valuable of constituents in this regard however, and its presence

is not essential to a first-class paving brick. Iron, when present, is usually in the form of hydrous peroxide or protoxide of a yellowish or bluish color. During the burning, the water of crystallization is expelled and the iron takes the form of the red peroxide, giving its color to the material in proportion to the amount present.

The presence of lime, however, affects this result as when this occurs a compound silicate of lime and iron is formed which is white or cream in color. A black color in brick is usually due to the presence of organic matter in the clay.

Potash and soda fuse at a lower temperature than the other constituents of clay, and their presence in suitable quantities is desirable for the manufacture of vitrified paving brick.

In Table No. 2 the analyses of various paving brick clays are given with that of some other noted clays for comparison. These analyses have been compiled from a variety of sources, too numerous to be mentioned in detail.

Character Due to Physical Condition.—The influence of physical condition is equally important to that of chemical character. Many of the clays from the older formations have been compressed and consolidated and form slates and other hard argillaceous rocks; others less compact form the shales, while others exist in a plastic form. There is a marked difference in their adaptability for manufacturing use under these varying conditions, and the methods of manufacture must be largely determined by them. If a clay is not found naturally in a plastic condition, it must be reduced to a finely divided state by mechanical means before it can be tempered and made into paving brick. While as previously noted, the fusing of clay depends on its constituents to a great extent, yet its physical condition also modifies this quality largely. Coarse clay, even with considerable of the fluxing materials, will resist considerable heat. The more finely clay is ground, the more easily it is vitrified and the tougher, stronger and more impervious its produce becomes. Fineness in grain is an essential feature of the best paving clays.

The ingredients of the clay exist in various forms which affect the clay and its product. The uncombined silica may be more or less finely divided and its condition has its effects on the action of the fluxes. In clays derived from feldspathic or micaceous rocks, undecomposed feldspars and micas sometimes occur. Lime, instead of being

TABLE No. 2.

Analysis of Paving-Brick Clay.

	Silica.	Alumina.	Perox. of Iron.	Protox. of Iron.	Lime.	Magnesia.	Potash.	Soda.	Water and Loss.	Undetermined.	Total.	Geological Source of Clay.
Kaolin	46.30	39 80	.....	.....	.....	.....	.....	.....	13.90	.....	100.00	Pure clay.
Stonebridge, Eng	67.34	23.03	.....	2.03	.....	.....	1.38	1.38	8.24	.....	102.02	Fire clay.
Mt. Savage, Md., non-plastic	50.46	35.90	.....	1.50	0.13	0.02	*Nil.*	*Nil.*	12.74	Mang. Oxide trace.	100.75	" "
Milwaukee (white brick)	38.22	9.75	2.84	1.16	3.24	15.83	2.16	0.65	2.80	Carbonate of lime. 23.20	99.85	Drift clay.
Philipsburg, N. J.	56.78	17.38	6.50	Phosphorus, 0.133	4.14	3.15	and organic matter, 3.427	and organic matter, 3.427	and carbonic acid. 7.600	Sulphur, 0.89	99.910	
Syracuse, N. Y.	67.67	11.67	6.53	.....	12.74	0.95	0.80	0.80	.....	.....	100.36	Salina shale.
Cumberland, W. Va.	69.02	22.07	4 53	.....	1.70	0.38	1.34	1.34	.....	0.96	100.00	Carboniferous.
New Brighton, Pa.	67.36	22.05	5.61	.....	0.86	0.36	2.70	2.70	.....	1.06	100.00	"
Canton, O	67.65	18.36	8.34	.....	0.80	1.02	2.58	2.58	.....	1.25	100.00	"
New Lisbon, O.	64.08	25.32	5.44	.....	0.30	0 29	0.63	0 63	.....	3.94	100.00	"
Middleport, O.	71.57	17.06	8.34	.....	0.50	0.58	0.56	0.56	.....	1.39	100.00	"
Brazil, Ind.	77.67	14.77	3.63	.....	0.38	0.27	2 43	2.43	.....	0.85	100.00	" and drift.
Columbus, O.	66.30	18.62	9.78	.....	0.40	0.84	1.89	1.89	.....	2.17	100.00	Devonian shale.
Akron, O.	60.05	20.00	6.82	.....	0.52	0.45	1.79	1.60	1.95	Sulphur, 1.95	101.11	Carboniferous.
Haydensville, O.	72.24	16.87	Iron 0.16	.....	0.50	trace	1.09	1.09	5.14	.....	100.00	"
Zanesville, O.	61.80	20.76	8.70	.....	1.38	1.09	1.44	1 44	.....	4.83	100.00	"
Robbins, Tenn.	70.57	15.19	7.97	.....	0.78	0 32	1.15	1.15	.....	4.02	100.00	
Rock Island, Ill	60 64	22.84	6.10	.....	0.24	0.75	3.28	0.57	5.00	.....	99.42	Carboniferous.
Galesburg, Ill.	68.69	17.95	7.25	.....	0.76	1.47	2.83	2.83	.....	1.05	100.00	"
Ottawa, Ill.	52.26	33.47	.....	4.51	3.01	2.91	1.10	1.10	2.74	.....	100.00	"
Clinton, Iowa	75.50	13.04	Iron 4 00	.....	0.50	.....	4.50	.....	3.00	.....	100.90	Hudson River shale.
Burlington, Ia.	77.40	11.74	3.29	.....	1.60	1.91	3.76	0.47	.....	.....	100.17	Carboniferous.
Bloomington. Ill.	67.80	11.55	4.31	.....	8.90	5.32	2.62	2.62	.....	.....	100.00	Drift clay.
Ft. Smith, Ark.	57.10	23.74	8.18	.....	0.53	1.04	1.53	0.87	7.21	.....	.....	Carboniferous.
Kansas City, Mo.	64.37	19.73	9.07	.....	0.82	2.32	1.89	1.89	.....	1.80	100.00	"
Leavenworth, Kan	58.45	21.96	Iron 8.43	.....	1.05	1.57	2.00	2.00	6.51	.....	99.94	"

finely divided, may occur as lumps or pebbles, in which condition it will unite with the other ingredients only on its surface, the balance burning into caustic lime, which on exposure will gather moisture and slack, disintegrating and crumbling the brick.

In general, a clay which will not readily melt and run, and yet one which will fuse and vitrify, but keep its shape, is essential to the manufacture of the best paving brick. Analysis and physical examination will point out the probability of the development of certain characteristics in the manufactured product, but, after all is done, the only thorough test is the working of the clay by suitable methods and its proper burning.

Mining.—The methods of mining clays depend entirely on their manner of occurrence and physical condition. With the softer clays, lying in beds which may be mined from bluffs or in open pits, the steam shovel may be used to excavate and deposit them in cars which is the cheapest method of handling large quantities of clay. With the harder clays the same method of loading may be utilized, but the clays must first be loosened by powder or dynamite. When a steam shovel is not used, wheel or drag scrapers may be utilized for short distances, or carts and wagons filled by shovelers may be used where the haul is longer. Winding drums with automatic dump cars, running by gravity to the pit, are popular in open-pit mining, and cars with horse-power are used in pit, drift or shaft mining. The various forms of electric motors and wire-rope tramways may also be utilized for the transportation of clays from pit to factory; all depending on the relative location and conditions governing the same.

The Manufacture of Brick.—The greatest diversity, both in the mechanical and chemical constitution of clays, renders the question of method of manufacture a difficult one, and a new factory, using a new and untried clay, is always more or less experimental; for the knowledge of the successful utilization of one clay is not wholly applicable to another.

All clays are improved by being loosely thrown up and exposed to the action of sun, rain and frost, all of which tend to disintegrate and make them more readily workable. Some clays are improved by thoroughly wetting and allowing them to lie in this condition for a day or more. This, to some extent, takes the place of weathering. The nearer homogeneous and fine grained a clay naturally occurs, the fewer processes necessary in handling it.

Soft, homogeneous clay may be run through rollers, to crush the lumps, and from the crusher it may go directly to the brick machine, although it is usually desirable to run it first through a pug mill for proper tempering. Lumpy clay of medium hardness can be pulverized by the granulator, but the indurated clays, shales, etc., are best treated by the dry or wet pan, the former being usually the most available for the rapid manufacture of large quantities of brick.

Indurated clay, when pulverized by one of the methods mentioned, is greatly improved by being tempered, or "pugged," 24 hours or more, before being used in the brick machine, although this is not usually done in the manufacture of paving brick. It should always, however, be reduced to an impalpable powder and thoroughly mixed with water before being molded into brick.

The common method of making building brick is by what is called the soft-mud process, in which the simplest of brick-making machinery is used. This is used only to a very limited extent in the manufacture of paving brick, Bloomington, Ill., being the only place familiar to the writer where this process is still used.

The dry-press process of brick manufacture has not as yet come widely into use for the manufacture of paving brick, although certain clays might be worked by this method. As a rule, however, a dry press does not bring the materials of the brick into such close union as is done by tempering with water. To be readily vitrified, a clay must contain a larger percentage of fluxing materials to be suitable for manufacture by this process. The writer understands that some paving brick are being made at Middleport, O., and Louisville, Ky., by this method, although he has not seen them.

What is known as the stiff-mud process is the one usually adopted for the manufacture of paving brick and seems to be the best adapted for the present circumstances of its manufacture.

The clay, if indurated, is first reduced to a powder, usually by means of the granulator or dry pan, and then thoroughly tempered in a suitable pug mill before passing to the brick machine. As a rule, the longer and more thoroughly the clay is worked or tempered, the more uniform and better will be the resulting product.

The auger machine has given the best satisfaction in the manufacture of stiff mud brick. Other systems have been tried, but they have been quite generally abandoned, and the machine-makers of the United States have adopted this type of machine almost universally.

On leaving the machine, the brick manufactured by this process are dry enough to handle, and they are placed on trucks or cars and conveyed at once to the dry house, unless the brick are to be re-pressed. After leaving the brick machine, some makers re-press their brick before drying. This forms them into more symmetrical shape and to a certain extent compresses them and aids in the removal of laminations. There is no doubt that the brick is somewhat improved by re-pressing, and it adds much to the appearance of the finished pavement, but it is not in general use at present. Many factories, however, furnish both common and re-pressed paving brick.

Drying.—Several systems of drying are in successful use among the paving-brick manufacturers. First, by a hot floor, which may be produced by furnaces or steam pipes under the floor over which the brick are hacked to dry. Second, by slatted floors under which are steam-piping and over which the brick are hacked to dry. Sometimes a modification of this method is used in which the dry house has racks from floor to ceiling on which the brick are placed for drying. The third system consists of a series of flues or tunnels into which the brick are run on cars, which will hold about 500 brick each. These tunnels are heated by means of furnaces or steam pipes. In all cases it is necessary to provide for a change of air as fast as the air in the dry house becomes saturated. The third method in one of its various forms seems best adapted for handling large quantities of brick, as the brick can usually be dried in from 18 to 36 hours by this method, where it takes from one to five days on the dry floor and from five to ten days if dried in racks. The saving in time and cost of handling by the use of the tunnel system is considerable, as the brick are placed directly on the cars from the brick machine, or re-press, and are not handled again until the car is run into the kiln with the dry brick ready to set. Any of the above methods of drying places the manufacture of brick independent of the weather.

Outdoor drying is a method too slow and uncertain for practical use in handling large quantities of brick. It is used, however, in many factories for the manufacture of building brick and may be used in small paving brick factories, for summer runs. A covered rack system is the best when outdoor drying is to be attempted.

Clays vary greatly in the facilities with which they may be dried. Clays highly aluminous must be dried with great care and often very

slowly, otherwise they warp and crack, while those with much silica will stand forced drying. Hence, the method of drying must be selected and so modified as to suit the clay used. Thorough drying greatly facilities the burning of the brick.

Burning.—There are two methods used for burning brick. The ordinary way in which common building brick are burned is in the up-draft or clamp kiln. This furnishes good ordinary brick, but it is difficult to raise the heat high enough to procure a large percentage of brick fit for paving purposes. It is almost impossible in this class of kilns to get a uniform product, the arch brick being very hard and the top brick poorly burned. Not over 40% of the brick in a kiln is available for "pavers." The consequence is that very few up-draft kilns are used for the manufacture of paving brick.

In up-draft kilns the fires are built in arches formed at the bottom of the pile of brick to be burned, by the method of setting the brick themselves. The heat rises through the spaces between the brick by the natural draft, which is regulated by a plaiting of brick laid flatwise and close together on top of the kiln. The brick in this plaiting may be set on edge, leaving a space of 2 ins. between brick when more draft is desired. In this manner the draft can be forced to such portion of the kilns as is necessary.

The down-draft kiln secures a uniform and much higher temperature, a large percentage of the brick, from 80 to 90% in a well-designed and well-constructed kiln, being suitable for paving purposes.

These kilns are built in the form of square, oblong or circular brick ovens, having fire pockets or furnaces built in their outer walls, at uniform distances about their circumference. The bottoms of the kilns are perforated more or less, to allow the gases to pass through the flues which are beneath the floor, and which lead to the chimney. The fire passes up from the furnaces into the kilns, then down through the brick to be burned to the flues, and thence to the chimneys. The draft in these kilns is much greater and can be better regulated, and as the brick are all inclosed within the kiln walls and roof, there is not the chance for the cooling of the outer brick as in the clamp kiln; hence, a more uniform and higher heat is possible. In either style of kiln, coal, oil or wood may be used as fuel, but the furnace should be constructed with due regard to the fuel to be used.

In burning brick, the fires must be started slowly in order to

"water-smoke" the brick without cracking them. In the brick, as they come from the machine, there is from 20 to 30% of water; about 50% of this water is the water of the pores, and is removed at a temperature of 100° Cent. (212° Fahr.). In the drying the balance is lost at a temperature of about 760° Cent. (1 400° Fahr.) in the burning. The former is sometimes called the water of the pores, the latter the water of composition. There is usually more or less water of the pores left in the brick after drying, although it is important to avoid this as far as possible. The loss of the physical and chemical water of the brick is accompanied by a corresponding loss in weight, and a considerable shrinkage in the dimensions of the brick. The final vitrification of the brick is a change in physical form, not in chemical composition, and consequently a change in dimension but not in weight may be noted.

The following is the record of the various weights and dimensions of one make of paving brick, which is in successful use in a number of cities, during the different periods of its manufacture :

TABLE No. 3.

Showing Various Weights and Dimensions of Brick during Different Stages of Manufacture.

Average of 12 samples.

	On leaving machine.	On leaving dryer.	Burned, not vitrified.	Vitrified.
Weight	6.46 lbs.	5.79 lbs.	5.08 lbs.	5.08 lbs.
Length	$8\frac{1}{2}$ ins.	8 ins.	$7\frac{7}{8}$ ins.	$7\frac{3}{4}$ ins.
Breadth	$4\frac{7}{16}$ "	$4\frac{3}{16}$ "	$3\frac{7}{8}$ "	$3\frac{3}{4}$ "
Thickness	$2\frac{1}{2}$ "	$2\frac{1}{4}$ "	$2\frac{1}{8}$ "	2 "

Slow firing is continued until the smoke passing off shows no further signs of the water-smoke (steam), after which the fires are gradually raised until the temperature throughout the kiln is sufficient to vitrify the brick, at which point it is held until they reach the proper point of vitrification, which is shown by the trial pieces or whole brick taken out through inspection holes in the top and sides of the kiln. After this, the kiln is gradually cooled down and the brick removed. Too rapid cooling is detrimental, as the brick are rendered very brittle. By slow cooling the brick are annealed and rendered tough. The burn-

ing occupies from two to four days for water-smoking, from four to six days for burning proper, and from three to five days for cooling.

Table No. 4 gives some details of the methods of manufacture as used at different paving brick factories in the United States.

Qualities of Paving Brick.—In all lines of practical work, experience with a given material is the only satisfactory method of determining the value of its various qualities. The individual and characteristic lines of the human face cannot be specified, and yet by them a friend is recognized and character is largely shown. In the same way it is difficult, if not impossible, to specify the limits of the qualities of brick necessary for paving purposes. As in the case of cement, stone and wood, paving brick must be selected with due reference to the uses to which they are to be put; that is to say, to the nature and extent of the traffic they are to encounter and the character of the climate they are to withstand. A large percentage of clays are undoubtedly capable of producing brick suitable for country roads, light suburban travel and residence streets of towns and cities. From many can be made brick which will withstand the moderate traffic of the smaller cities of from 30 000 to 50 000 inhabitants. It is the writer's belief that clays can be found which, if properly manufactured and properly placed in the pavement, will out-rival granite under the heaviest traffic, and some brick are now made which it is believed would prove economical under such traffic.

The color in a brick is no criterion of its value as a paving brick when comparing brick of various makes; but, in inspecting brick from a single factory, the color will usually furnish a fairly safe guide as to the relative hardness, when the inspector is thoroughly acquainted with the particular manufacture. The knowledge gained regarding the relation of color and quality in inspecting one make of brick, however, can seldom be used in that of another make from a different locality. The brick vary in color according to the amount of burning. As a rule, the depth of color increases with the increased burning. This is true only where the brick are not salt glazed, which should never be allowed in those for paving purposes.

Another criterion as to the character of any single make of brick is the comparative size. As is seen in Table No. 3, the harder a brick is burned, the smaller it becomes up to a certain limit which must be determined for each make of brick. Hence, in the inspection, the un-

TABLE No. 4.

Showing Methods of Manufacturing Paving Brick.

Locality.	Kind of Clay.	Geological Origin.	Methods of Manufacture.	Method of Drying.	Character of Kilns.
Brazil, Ind.	Fire clay and surface clay mixed.	Carboniferous and drift.	Dry pan. Pug mill. Stiff mud machine.	On slat floor.	Down draft.
Decatur, Ill.	Surface clay.	Drift period.	Roller crusher Stiff mud machine.	On rack in steam-heated dry house.	Down draft.
Bloomington, Ill.	Surface clay.	Drift period.	Vertical pug mill. Soft mud machine.	In yard.	Up draft.
Galesburg, Ill.	Shale clay.	Carboniferous.	Dry pan. Pug mill. Stiff mud machine.	On cars in drying tunnels.	Square down draft.
Galesburg, Ill.	Shale clay.	Carboniferous.	Dry pan. Pug mill. Stiff mud machine.	On hot floor heated by furnaces below.	Round and square down draft.
Evansville, Ind.	Shale clay.	Carboniferous.	Dry pan. Mixer. Pug mill. Stiff mud machine.	Tunnel dryer.	Square down draft.
Rock Island, Ill.	Shale clay.	Carboniferous.	Dry pan. Screen. Pug mill. Stiff mud machine.	Tunnel dryer.	Round down draft.

duly large brick may be unhesitatingly rejected as too soft. As in the manufacture of brick, the die constantly wears larger and must be replaced occasionally by a new one, a change in size from this cause must not be confused with that due to under-burning.

In general, a brick for paving purposes must be homogeneous, free from uncrushed or lumpy material, especially if such material is not united by vitrifaction with the balance of the material of the brick. Vitrifaction is desirable, but not essential, as many paving brick, especially those made in West Virginia, cannot be classed under this head. These are made from clays very near fire clays in character and are giving very good satisfaction, at least under moderate traffic. "Vitrified firebrick" is a misnomer, as fire clays are so named on account of their withstanding high heats without vitrifaction.

In this country, the climate in which the majority of paving brick is used is so severe that the disintegrating effects of frost are the most severe test a paving brick must stand, especially in streets of moderate traffic. Hence, one of the first requisites of such a brick must be that it will not absorb a large percentage of water, for if it should, as has been shown by experience, the freezing of the absorbed water will cause rapid crumbling. The permissible ratio of absorption cannot be definitely fixed at any given percentage, for it is found that this ratio varies with different classes of brick. One class of brick, which seems to be uniformly made from clays which approach near to fire clays in character, will admit 4 or 5% of water and still not crumble through the action of frost; while others, if not burned hard enough to render them impervious to more than $2\frac{1}{2}$ to 3%, will be rapidly disintegrated by the frost.

With the auger machine, if the clay is not properly tempered, a core or lamination is produced in the brick which prevents proper cohesion of the material and affords a seam where the frost may enter. It is inadmissible in paving brick. Fire cracks, caused by too rapid firing, if small and superficial, are not of much importance, but they should be limited in number and extent.

The presence of lime, in itself, as has been before stated, is not detrimental if in limited quantities, yet this must not exist as lime pebbles or it will render the product entirely unfit for use by disintegrating and crumbling it.

The specific gravity of a brick is somewhat of an index of its com-

parative value, as the more material contained in it, the greater its density, and other things being equal, the greater its resistance to abrasion, crushing, etc. A certain amount of toughness is desirable in a paving brick, to prevent splintering and breaking under traffic. This quality, the writer believes, is at present overestimated, as when laid in the street a brick can splinter only to a limited extent at the corners after which the shape assumed is such as to greatly resist abrasion.

The brick must be of sufficient transverse and crushing strength to resist all the demands of traffic with a sufficient factor of safety. Further than this, these qualities are of little material value, although their great development, together with other qualities in equal degrees, is evidence of high perfection in the class and manufacture of the brick.

Testing the Material.—In making tests for relative qualities of brick, nothing will take the place of experience. A few general suggestions, however, for making ready tests, such as are now in use, are offered with the hope that they may prove serviceable.

The personal error is so large in the testing of material that no attempt should be made to compare the results obtained by an inspector unfamiliar with the methods and results of making such tests, with the published tests of experienced observers. Instead, however, standard makes of brick should be tested in connection with samples submitted, by means of which results may be checked and a comparative relation established with other experiments.

Prof. I. O. Baker has pointed out the wide variation obtained in the crushing strength of brick. He obtained a strength of from 7 000 to 9 000 lbs. per square inch, with ordinary care in the preparation of the surfaces of the material to be tested, and with the same material, with beds more carefully prepared, strengths ranging from 16 000 to 21 000 lbs. were obtained. The variation in strengths shown by testing quarters, halves, three-quarters and whole brick, or brick on side, edge and end, has also been shown by Prof. Baker to be fully as great. It is desirable that a uniform method of testing be established as far as possible in order to allow a comparison of results. The test for crushing strength is believed by the writer to be of little or no value unless in comparison of the values of high-grade paving brick. The test is difficult of application, requiring expensive machinery; and unless carefully made by skilled observers, under definite given conditions, the results are very

uncertain and unreliable. The transverse strength can be determined with greater accuracy than the crushing strength; it also represents both the compressive and tensile strength of the material, and is, therefore, a better test of the qualities of the brick. The transverse strength may be determined by the ordinary formula for transverse strength $R = \frac{3\,l\,W}{2\,b\,d^2}$ where R is the modulus of rupture, l the length between supports, b and d the breadth and depth of the brick, and W the load applied.

Prof. A. N. Talbot suggests (*Transactions* Am. Soc. C. E., Vol. XXVI, p. 415) the following method for applying this test:

"This test may be easily made, even if a testing machine is not at hand, as follows: Caliper the plunger of a hydraulic press, such as may be found in the machine-shop of any city, and attach a pressure gauge. Place the end of the plunger against a knife edge (easily cast) resting on the middle of the brick. Then the brick may rest on two knife edges placed for uniformity 6 ins. apart, and the stress of the plunger may be applied. After finding the pressure of the plunger, the modulus of rupture is easily calculated."

In testing for ratio of absorption, the brick should be placed in a drying or common oven and kept at a temperature of about 100° Cent. (212° Fahr.), for 10 hours or more if they have previously been saturated. They should then be weighed, and after the weight is carefully determined, placed in a vessel of water and kept for 24 hours at a temperature of about 15° Cent. (60° Fahr.), after which they should be taken out, the surface water carefully removed and again carefully weighed. The gain in weight, divided by the original weight, will give the ratio of absorption.

The presence of caustic lime is easily told by immersing the brick from one to four days in water. If caustic lime be present, it will make its appearance by breaking or cracking the brick or by "poppers" showing on the surface.

The specific gravity can be readily determined by weighing the brick, air dried W, after immersion W', and in water W'', and substituting in the formula—

$$\text{Specific gravity} = \frac{W}{W' - W''}.$$

The test for toughness or abrasive strength is usually made in an ordinary foundry tumbler. The brick should be tested a few at a

TABLE No. 5.

No.	Material—How Made.	How Burned.	Specific Gravity.	Absorption, percentage by weight of brick.	Transverse Strength.	Crushing strength cubes, plaster surface.	Crushing strength cubes, rubbed surface.	Observer.
1..	Drift Clay.....	Down draft.....	2.10	4.5	1 712	13 085	.....	I. O. Baker.
2..	" Stiff mud.....	Down draft.....	2.21	1.3	1 496	10 545	.....	" "
3..	" Soft mud.....	Up draft.....	1.87	4.8	1 429	6 190	.....	" "
4..	Fire Clay, Stiff mud, repressed....	Down draft.....	2.13	3.0	2 428	.....	13 402*	M. D. Buck.
5..	" Stiff mud.....	.....	2.18	2.9	2 197	.....	13 402*	" "
6..	" Stiff mud.....	.....	2.07	2.35	1 863	.....	11 688	" "
7..	Shale Clay, Stiff mud.....	Down draft.....	2.20	.01	2 645	.....	12 417	Gates and Page.
8..	" Stiff mud.....	" "	2.31	1.12	2 822	.....	13 402*	M. D. Buck.
9..	" †Stiff mud, repressed....	" "	2.21	1.20	1 680	5 260	12 010‡	I. O. Baker.
10..	" ‖.....	.....	2.29	.58	2 264	.....	13 402*	M. D. Buck.

* Tested to the limit of testing machine without crushing.
† This clay is from the Huron shale, Devonian period.
‡ This test was made by M. D. Buck.
‖ This clay is believed to be from the disintegration of the Salina shale.

time, with about 100 lbs. of "foundry shot," weighing not more than ½ lb. to the piece. Heavy pieces of iron should not be used in this test, as they break the brick to pieces instead of wearing it. The different shapes of brick are apt to make a material difference in their wear during the first half hour. This is caused by some brick being manufactured with rounded edges, and some with square edges; the latter, being more easily broken or abraded, cause a greater loss in the material so made. For this reason they should be weighed after the first half hour, and the results of the second or third half hour used for comparison.

Table No. 5 is derived mostly from experiments of Prof. I. O. Baker and by M. D. Buck, C. E., and will give a general idea of the qualities of some paving brick in more or less successful use.

Table No. 6 is from the experiments by Prof. I. O. Baker, made under conditions closely resembling those recommended in this article. This table will give an example of the relative resistance to abrasion of brick during the first, second and third half hours in the rattler. It will be noted that brick No. 5, with rounded edges, lost only about the same percentage during each of the half-hour tests.

TABLE No. 6.

Resistance of Brick to Abrasion and Impact.

No.	Material.	Quality.	Loss in per cent. of the original weight during—		
			1st half hour.	2d half hour.	3d half hour.
1.	Drift clay.....	Paver.....	2.0	0.8	0.8
2.	"	Under-burned.....	4.9	3.0	2.6
3.	"	Paver.....	2.1	1.3	0.7
4.	"	Under-burned.....	3.6	2.5	2.0
5.	*Shale clay.....	Paver.....	0.5	0.3	0.4
6.	"	"	3.1	1.5	1.3
7.	Fire clay.....	"	4.2	2.0	1.2

* Rounded edges.

Specifications.—Specifications should so define and limit the qualities of material to be used as to protect, on the one hand, parties for whom the work is done from the use of improper material, and the contractor, on the other, from capricious and arbitrary requirements.

The large majority of specifications for paving brick is entirely inadequate. They are vague and often meaningless, and in order, while

still in this condition, to protect the city from qualities of material, of which the municipal officers are (judging from the style of specifications) presumably ignorant, they are drawn so as to leave the selection and rejection at the discretion of such officers. The writer saw at one place 60 000 brick rejected and ordered off the street under such conditions by officers, who believed them to be defective. Brick of a poorer class of material, but having a more uniform and smoother form, were selected and used in their place. This fact was acknowledged by the same officers within a year after its occurrence, when the qualities of the two bricks had time to develop in the pavement. Certainly such a state of affairs is undesirable, and an attempt should be made to specify the qualities of the material, keeping, of course, well within the bounds of safety and possibility.

It should be remembered that each additional requirement cuts out certain classes of brick, lessens the competition, and in that way, and by reason of the extra cost in the manufacture of a higher grade article, increases the price of the finished pavement.

It must also be observed that with the present demand for paving brick and the state of the manufacture in many places where factories have been recently established, it will often be impossible to obtain brick which will fall within the higher limit herein named. Hence, the engineer should assure himself of the best quality of brick which can be obtained in sufficient quantities for his use, before adopting specifications calling for any particular grades of paving brick.

The following is suggested as an outline for specifications, to be modified more or less in accordance with the character of the work and the availability of material.

All paving brick must be homogeneous and compact in structure, free from loose lumps of uncrushed clay or from laminations caused by the process of manufacture, or fire cracks or checks of more than superficial character or extent. All brick so distorted in burning as to lay unevenly in the pavement shall be rejected. All brick shall be free from lime or magnesia in the form of pebbles and shall show no signs of cracking or spawling on remaining in water 96 hours. They shall be subjected to the following test for abrasion. Five brick shall be placed in a rattler which shall not exceed 28 ins. in diameter and which shall contain 100 lbs. of foundry shot of not more than $\frac{1}{4}$ lb. weight each, and said rattler shall revolve at a rate of not more than

25 revolutions per minute. They shall endure this test without sustaining a loss of more than from 1 to 2%* per half hour after the first half hour.

The brick shall have a specific gravity of not less than 2.00 to 2.20.* They shall not absorb more than from 1 to 5%* of water when dried at 100° Cent. (212° Fahr.) and immersed for 24 hours in water. They shall not crush under less than from 8 000 to 12 000 lbs.* per square inch when tested by preparing 1½-in. cubes with beds carefully rubbed to parallel and equal faces and tested between adjustable plates. They shall show a modulus of rupture of from 1 400 to 2 000 lbs.* per square inch when tested in full size on their side, the same to be computed by the formula $R = \frac{3\ l\ W}{2\ b\ d^2}$ in which R is the modulus of rupture, l the length between supports, b and d the breadth and depth, and W the load. All brick tested shall show an average equal to the limits named above, but a variation in individual specimens of not to exceed 10 to 20%* of the above limits will be allowed.

No brick not hitherto successfully used at other places will be accepted without a chemical analysis certified to by some competent chemist of reputation, which analysis shall show a chemical composition not differing materially from that of other paving brick in successful use.

All brick shall have a proper shrinkage and shall not differ materially in size from the accepted samples of the same make, unless said change is due to a change in die, such change to be acceptable to the city. Nor shall they differ greatly in color from the natural color of the well-burned brick of its class and manufacture. These qualifications shall be compared with the brick deposited at the time of letting or with others afterward substituted by the consent of both parties hereto.

The pavement shall be guaranteed for a term of two years from the date of its completion, and all brick injured by frost or shown to be defective in character or quality during this time shall be replaced by suitable material at the contractor's expense.

---

*These figures include the limits from which the limit to be specified should be selected, in accordance with the qualities desired or possible under existing circumstances.

NOTE.—The writer believes Professor I. O. Baker first suggested approximately these limits for ratio of absorption and transverse strength. He also suggested that the limits be average limits from which a limit of variation be allowed which shall not exceed 20% on any sample tested.

The Pavement.—The use of brick for paving in the United States has been confined to the last two decades. Its first use was at Charlestown, W. Va., and at Bloomington, Ill., about 20 years ago. From these points, with their small beginnings, its use has spread until at present it is one of the most popular and widely used of all paving material.

A discussion of the principles that underlie brick paving would be a discussion of the principles of all paving. This material simply offers a surface covering, smooth and even, but not slippery, durable, economical and highly sanitary. It must be laid on a foundation drained and prepared as for all pavements. Beyond this, the success of the pavement depends on the proper selection of the material. With poor material it will prove a failure, as has been shown by the attempt to utilize common building brick at Nashville, Tenn., and elsewhere. With proper material it is an established success, and is destined, with the improvement in manufacture and the bettering and cheapening of the product thereby, to rank first in economy and availability of all paving material. In the majority of places it offers a possible local industry, when the availability of the local geological resources are better known and appreciated, and the different methods of utilizing them in manufacturing are more thoroughly understood.

In first cost the pavement depends on the nearness of the manufactories and the local resources suitable for foundations.

"For light traffic the fragmentary materials (rubble, gravel, sand, etc.), or sand with a layer of brick laid on their side, or 6 ins. of concrete, make good foundations, the selection depending on the local resources.

"For medium traffic, 9 ins. of stone or gravel, or 6 ins. of gravel or stone, with a layer of brick laid on their side, bedded in sand, or 6 ins. of concrete, will give good results.

"For heavy traffic the stone or gravel should be at least 1 foot in thickness, or the concrete at least 9 ins.

"All subfoundations which are retentive of water should be properly and thoroughly drained."*

In the average city the network of pipes and conduits laid below the street surface is the cause of frequent disturbances of the pavement which is often the leading factor in its destruction. The facility with which pavements can be taken up and replaced becomes, under such circumstances, quite important. In this, brick pavement is second to none. The brick, being uniform in size and shape, can be

* From a previous paper by the writer.

returned to their places by unskilled labor, an important point in smaller towns and cities. This is especially true if the fragmentary foundations are used, and if sand only is used in the joints. Where either coal tar or cement grout is used in the joints, the brick taken up are difficult and often impossible to clean, and new material has to be substituted. With sand in the joints the old material is readily cleaned, and the sand, in two weeks' time after laying, renders the pavement as impervious to the seepage of surface waters as the tar or cement.

The durability of brick pavements is a subject open to inquiry, for the limited time they have been in extensive use has been too short to answer this from practical experience.

The destruction of a pavement results from (1) the crushing by the wheel load; (2) the abrasion by friction of passing vehicles and the slipping of horses' shoes; (3) the impact due to the passage of loads over a rough surface, and the impact from the shoes of horses.

It has been found that the best paving brick will crush under loads varying from 8 000 to 18 000 lbs. per square inch, while granite will crush under loads varying from 13 000 to 22 000 lbs. per square inch. Brick, therefore, shows a strength sufficient to resist, with a large factor of safety, any load to which the pavement will be ordinarily subjected. The rattler test, the only test so far attempted for determining resistance to abrasion and impact, gives the comparative resistance of brick and granite (according to Prof. I. O. Baker), as follows:

Loss of granite in 1½-hour rattler test, ½ to 3½ per cent.

Loss of paving brick in 1½-hour rattler test, 2½ to 5 per cent.

The smoothness of brick will, in the opinion of the writer, more than overcome the difference in abrasive resistance of the granite. A loaded wheel as it passes over a rough pavement causes impact in proportion to the load and the degree of roughness of the pavement, and is the principal cause of wear in granite and cobblestone pavements, which is largely avoided with the smooth surface of brick.

The writer estimates the life of first-class brick pavements to be: for light traffic, 35 to 50 years; for medium traffic, 20 to 25 years; for heavy traffic, 10 to 15 years.

Prof. I. O. Baker, in his valuable pamphlet on "Brick Pavements," from which the writer has hitherto quoted, publishes a table based on his experiments, showing the probable length of life of brick in certain

streets of various American cities. From this table, Table No. 7 is reduced, somewhat changed in form from the original. The table is largely based on the tonnage observations of Captain F. V. Green.

The smoothness of brick renders it free from much of the objectionable noise of the rougher pavements.

Its freedom from decay, and its non-absorption of water, are sanitary qualities of considerable value. It produces little dust of its own and as it is not retentive of mud and dust, it can be readily cleaned.

Being smooth without being slippery, it offers comparatively little resistance to traction, while affording a fair foothold for horses.

Table No. 8 gives a concise statement of the manner of laying brick pavements in a number of cities of the United States, which will render the ordinary methods of utilizing this material quite readily understood.

TABLE No. 7.

SHOWING PROBABLE LIFE OF SEVERAL SAMPLES OF BRICK IF LAID IN CERTAIN STREETS OF PROMINENT CITIES OF THE UNITED STATES.

CITY.	STREET.	Width in feet.	DAILY TONNAGE.			Approximate life of brick pavements. Number of years required to wear off 50% from certain paving brick.				
			Total.	Per vehicle.	Per foot of width.	1	2	3	4	5
New York	Broadway, near Pine	40	10 905	1.39	273	9	11	19	7	4
New York	Fifth Avenue, opposite Worth Monument	40	3 740	.68	94	28	31	56	19	12
New York	Wall, corner Broad	27	2 357	1.00	87	30	34	60	20	13
Boston	Devonshire, opposite Post Office	27	5 301	.99	196	14	15	27	9	6
Boston	Washington	39	2 938	.80	75	35	38	70	24	15
Boston	Court Square	24	744	.67	82	83	91	165	53	35
New Orleans	Tchoupitoulas, near Poydras	40	6 204	1 81	155	17	18	34	12	7
New Orleans	St. Charles, near Washington	30	1 065	.94	35	76	83	151	51	32
Chicago	Wabash, near Lake	50	7 561	2.08	151	18	19	35	12	8
Chicago	Clark, near Madison	45	6 398	1.46	142	19	21	37	13	8
Chicago	La Salle, near Locust	36	2 756	.90	77	34	38	68	23	15
Chicago	Dearborn, opposite Washington Park	38	2 604	1 11	69	38	42	76	26	16
Philadelphia	Broad, in front of Pennsylvania Railroad Depot	65	9 237	1.52	142	19	21	37	13	8
Philadelphia	Chestnut, corner of Fourth	26	1 928	1.06	74	36	39	71	24	15
St. Louis	Locust, near Beaumont	36	3 691	1.13	103	26	28	51	17	11
St. Louis	Pine, near Garrison	36	2 554	1 16	70	38	42	76	26	16
Louisville	Main, near Third	61	4 176	1.25	69	39	42	76	26	16
Washington	Fifteenth, opposite Treasury	70	4 622	1.02	66	41	45	81	27	17
Washington	Sixth, between Pennsylvania and B	60	1 289	1.01	21	126	139	252	84	53
Buffalo	Main, near Swan	56	2 613	.83	47	57	62	113	38	24
Buffalo	Linwood, near Ferry	38	825	1.47	22	121	133	241	81	51
Omaha	Douglass, near Fifteenth	63	2 967	.62	47	57	62	113	38	24

Nos. 1 and 2 were made from drift clays.
Nos. 3 and 5 " " " shale clays.
No. 4 was made from semi-fire clay.

TABLE No. 8.

Details of Brick Paving as in Use in Many American Cities.

Locality.	Years in Use.	Foundation.	Depth of Sand Cushion.	Size of Paving Brick.	Filling of Joints.	Average Cost per Yard.	Brick—Where Made.
Atchison, Kans.	5½	4" of sand, course of brick flatwise.	1"	.....	Sand.....	$1 65	Atchison, Kan.
Alton, Ill.	2	6" broken stone, course of brick flat	1"	2¼ x 3¾ x 7⅞	"	2 16	Galesburg, Ill.
Bloomington, Ill.	18	Cinders 2" sand 2" course of brick flatwise.....	1"	" " "	"	1 40	Bloomington, Ill.
Burlington, Ia.	5	6" broken stone, cinders or sand, with course of brick flatwise.....	1"	2¼ x 4½ x 8½	"	1 65	Burlington, Iowa.
Clinton, Ia.	4	6" broken stone with sand washed in.....	.....	2¼ x 3¾ x 7⅞	"	1 35	Rock Island, Ill. Galesburg, Ill. London Mills, Ill.
Cedar Rapids, Ia.	.....	2½" sand with course of brick flatwise.....	1"	" " "	"		
Council Bluffs, Iowa	4	4" sand.....	.....	2¼ x 4 x 8	Sand.....	1 32	Council Bluffs, Iowa.
Columbus, O.	7	Broken stone or concrete.....	.....	2 x 4 x 8 to 3 x 4½ x 9	Tar or grout.....	1 50–2 25	Columbus, O. Zainesville, etc., O.
Cincinnati, O.	3	6" concrete	.....	3 x 4 x 9	Coal tar.....	2 50	Ohio factories.
Charlestown, W Va.	22	3½" sand and tarred boards.....	1½"	2 x 4 x 8	Sand.....	1 15	Charlestown, W Va.
Detroit, Mich.	3	....	.....	2¼ x 4 x 8½	Coal tar	2 00	Ohio and Pennsylvania.
Davenport, Ia.	5	8" broken stone, sand washed in 6" broken stone, course of brick flatwise	.....	2¼ x 3¾ x 7⅞	Sand.....	1 38 1 70	Galesburg, Ill.
Dayton, O.	.....	6" concrete.....	2"	" " "	Tar or grout.....	.....	" "
Dubuque, Ia.	6 mo.	" "	.....	" " "	Sand.....	1 69	" "
Des Moines, Ia.	.....	4" sand, course of brick flatwise....	1"	" " "	"	.....	Des Moines, Ia. Galesburg, Ill. Boone, Ia.
Evansville, Ind.	3	6" concrete.....	.....	2½ x 4½ x 8½	Sand	1 70	West Virginia, and Evansville, Ind.
Evanston, Ill.	2						
Fort Wayne, Ind.	1	6" broken stone.....	2"	2½ x 4 x 8½	Sand.	1 55	Bucyrus, O.
Findlay, O.	3	8" broken stone, 4" gravel or sand.	.....	2½ x 4⅛ x 8½	Coal tar.....	.....	West Virginia.
Fort Smith, Ark.	3	6" concrete	2"	2 x 3¾ x 7¾	Sand.....	.....	Fort Smith, Ark.
Galesburg, Ill.	6	6" sand, course brick flatwise.....	1"	" " "	"	1 40	Galesburg, Ill.
Hannibal, Mo.	2	4" broken stone, 3" sand, course of brick flatwise	1"	" " "	"	.....	" "

Legend
Areas of Carboniferous deposits
Limit of drift
Cities where Paving Brick Factories are located
Cities having Brick Pavements
Cities having Factories and Pavements
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
L. ERIE
ONTARIO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
INDIAN TERRITORY
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
TENNESSEE
KENTUCKY
OHIO
INDIANA
ILLINOIS
WEST VIRGINIA
PENNSYLVANIA
N.Y.
N.J.
Minneapolis
Wyoming
Drift Area
Sioux City
Sargents Bluff
Boone
Madrid
Dubuque
Redfield
Clinton
Aurora
Chicago
Grand Rapids
E. Saginaw
Detroit
Toronto
Rochester
Syracuse
Rome
Boston
Springfield
Hartford
Council Bluff
Creston
Lincoln
Nebraska City
Beatrice
Oskaloosa
Ottumwa
Burlington
Fairfield
Monmouth
Galesburg
Rock Island
Peoria
Bloomington
Lincoln
Springfield
Decatur
Quincy
Hannibal
Jacksonville
Litchfield
Alton
St. Joseph
Atchison
Leavenworth
Kansas City
Topeka
Marshall
Moberly
Sedalia
Ft. Scott
Springfield
Ft. Smith
Memphis
Mt. Vernon
Terre Haute
Sullivan
Brazil
Vincennes
Evansville
Louisville
Cloverport
Elkhart
South Bend
Fort Wayne
Michigan City
Fremont
Findlay
Bucyrus
Madison
Lafayette
Danville
Indianapolis
Columbus
Dayton
Cincinnati
Lancaster
Logan
Akron
Cleveland
Norwalk
Mansfield
Canton
Orrville
Ashtabula
Meadville
Franklin
Oil City
Youngstown
Beaver
Liverpool
Allegheny City
Shawmutt
New Cumberland
Wellsburg
Steubenville
Wheeling
Philadelphia
Wilmington
Washington
Parkersburg
Point Pleasant
Huntington
Charleston
Staunton
Lexington
Nashville
Knoxville
Mobile

TABLE No. 8—(*Continued*).

Locality.	Years in Use.	Foundation.	Depth of Sand Cushion.	Size of Paving Brick.	Filling of Joints.	Average Cost per Yard.	Brick—Where Made.
Hartford, Conn	6 mo.	Sand		3 x 4 x 9	Tar	2 75	Columbus, O.
Indianapolis, Ind	2	6" concrete		2¼ x 4¼ x 8¼	Tar and grout	2 40	Vetersburg and Brazil, Ind. Canton, O.; Ottawa, Ill.
Jacksonville, Ill	4	6" coal cinders, 1" sand, course brick flatwise	1"	2¼ x 4 x 8		1 30	Jacksonville, and Virden, Ill.
Kenosha, Wis	6 mo.	6" concrete or broken stone	1"	2¼ x 3¾ x 7¾	Sand		Galesburg, Ill.
Keokuk, Ia	6 mo	5" broken stone, 3" sand, course of brick flatwise	1"	2¼ x 4 x 8	"	1 68	Burlington, Ia.
Lafayette, Ind	3	8" gravel, 2" sand, course of brick flatwise	1"	" " "	"		Danville, Ill.
Louisville, Ky	1½	6" concrete		2½ x 4½ x 8½	Coal tar	1 65	Clovesport, Ky. New Cumberland, W. Va.
Mobile, Ala	5	Sand and course of brick flatwise	1"	2½ x 4 x 8	Sand	1 50	
Massillon, O	3	6" sand	2"		Sand and tar		Massillon, O.
Memphis, Tenn	4	6 to 9" concrete		2½ x 4 x 8¾	Asphalt	2 78	West Virginia, and Robbins, Tenn.
Ottawa, Ill	2	6" sand, course of brick flatwise	1"	2½ x 4 x 8	Sand	1 37	Ottawa, Ill.
Omaha, Neb	5	6" concrete	2"	2¼ x 4 x 8	Sand	1 95	St. Joseph, Mo.; Atchison, Kan.
Peoria, Ill	6	6 to 8" gravel or 6" concrete	1"	4 x 5 x 12	"	1 75	Peoria, Ill.
Quincy, Ill	6	8" stone, 2" sand, course of brick flatwise	1"	2½ x 3¾ x 7¾	"		Galesburg, Ill.
Rockford, Ill	1½	6" broken stone, 2" sand				1 34	Rock Island and Galesburg, Ill.
		4" broken stone, 2" sand, 1 course of brick flatwise	1"	2½ x 3¾ x 7¾	Sand	1 74	
Rock Island, Ill	4	6" broken stone, 2" sand, course of brick flatwise	1"	" " "	"	1 65	Rock Island, Galesburg, Ill.
		6" broken stone, 2" sand	1"	" " "	"	1 40	Rock Island Ill.
Wilmington, Del	2½	Broken stone and sand		2½ x 4¼ x 8¼	Sand, tar or grout	2 00	West Virginia and Rhode Island.
Scranton, Pa	5	Gravel and sand, or 4" concrete		2½ x 4 x 8	Tar and sand	2 10	New Cumberland, W. Va. Springfield, Ill.
Springfield, Ill	6	6" cinders		2 x 4 x 8	Sand	1 50	Vinden, Peoria, Ill.
Terre Haute	1	8" rubble	2"	2½ x 4¼ x 8½	Grout	2 25	Canton, O.; Brazil, Ind.
Wheeling, W. Va	10	8" gravel	2"	2 x 4 x 8¼	Coal tar	1 35	New Cumberland, W. Va.

Note.—The above table was derived partially from data furnished by E. R. Ruttan, City Engineer of Winnipeg, Manitoba.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

629.

(Vol. XXIX.—September, 1893.)

CARBON AND ITS USES IN ELECTRICAL ENGINEERING.

By CLARENCE M. BARBER, C. E., Member of the Civil Engineers' Club of Cleveland.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In the year 1810, Sir Humphry Davy connected the poles of a battery of 2 000 elements by two charcoal points, and produced one of the most brilliant artificial lights that had doubtless ever been seen.

So little value was attached to this experiment that it was merely entered in the note book of the great physicist, and remained there apparently unnoticed until 12 years later, when it appeared as a communication to the Royal Society. Scarcely do we find a more striking example of the great advancement in electrical science than when we note that this bright spark has grown in strength and beauty, until now there are required to feed its ever-spreading rays 200 000 000 of carbon pencils for the present year in the United States alone.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

In electrical engineering, the term carbon is used to designate an artificial solid, which, through mechanical or chemical means, is derived from some of the natural forms of carbon. It is moulded under great pressure into cylindrical pencils for arc lighting, or into rectangular blocks or plates for battery or other uses. It is not the purpose of this paper to describe minutely the process of making carbon, nor is it necessary, as there are published descriptions which cover the ground fairly well. However, an outline of the general principles may not be out of place.

The materials usually employed are coke and pitch. The coke should be as free from solid impurities as is obtainable. Petroleum coke is largely used, although other varieties are often sufficiently pure for the purpose. It is ground to powder, and the volatile components are driven off by heating in retorts. Melted coal tar pitch is then thoroughly mixed with it, and for some kinds of carbon lampblack is also added. The mixture is then cooled, again ground to powder, and is then ready to be moulded or forced.

The process of moulding consists of filling the material into steel moulds, which are made in two equal parts, so arranged that the lower half of the mould will contain a sufficient quantity of the material for the entire charge. The upper half is then placed in position upon its counterpart, the mould is placed in a furnace and heated sufficiently to soften the fusible ingredients. It is then put under a pressure of about 400 tons, after which the 16 pencils, or carbons as they are called, are removed from the mould. After cooling they are ready for the next process, which consists in handling the carbons one by one, examining and trimming off the webs which usually occur between the individual pencils as they lie in the mould; they are then packed in furnaces holding from 30 000 to 50 000, where they are baked at a high temperature for about 100 hours. After cooling for a like period they are sorted for straightness. A portion are then sent to the consumer, but a large portion are first coated with copper.

The process of forcing is proximately the same as that of moulding until the material is ready for the moulds; then, instead of being moulded, it is heated and made into cylindrical plugs, which are placed in a heavy iron cylinder, and, by means of a plunger driven by hydraulic pressure, the plastic material is forced through a steel-bushed orifice and comes out in the shape of a continuous cylinder,

which is cut to the lengths desired. The carbons are then sent to the furnaces, and from this point the process is the same as for the moulded.

The forcing process permits of a wide range of shapes, as by changing the size of the steel-bushed orifice, cylindrical carbons can be forced having a diameter of $\frac{1}{16}$ in., and from this size up to or even above 4 ins. in diameter. Many other shapes besides cylindrical can also be made, such as plates that are not much over 4 ins. wide and of a thickness of from $\frac{1}{8}$ to $1\frac{1}{2}$ ins. or over. These are cut into short lengths and used for dynamo or motor brushes. Plates as small as $\frac{1}{4}$ x $\frac{1}{8}$ in. are also forced for small generator or motor brushes.

There is a great difference in density and structure between moulded and forced carbon. The pressure under which moulded carbon is made is about 8 300 lbs. per square inch, while by the forcing process the pressure required is double or three times as great. By the method of forcing, the material is crowded together as it is pressed toward the small end of a conical chamber and is finally forced out at the vertex, thus giving a combination of lateral and end pressure.

By the method of moulding, the carbons receive side pressure only. Under the side pressure, the material tends to laminate in planes parallel to the axis of the carbon; while under end pressure, the planes of lamination are at right angles to the axis. As usually made, the pressure is not sufficient to produce distinct lamination; but it is evident that the structure of the material is inclined toward this class of formation, as in the case of slate rock which is laminated in planes at right angles to the lines of pressure. Under certain conditions, lamination may be observed both in moulded and forced carbon.

Carbons as they are usually made for arc lamps are about $\frac{7}{16}$, $\frac{1}{2}$ or $\frac{5}{8}$ in. in diameter, by about 12 ins. in length. In some cases pairs are used, a carbon 7 ins. and one 12 ins. usually constituting a pair. Besides those there are several other sizes in use; for searchlights and for many of the large lighthouses, carbons as large as $1\frac{1}{2}$ ins. in diameter, and often larger, are employed.

In addition to the ordinary pencils, many other forms may be moulded, such as cups or crucibles, or almost any design where the material can be retained in moulds and submitted to great pressure. Plates are made 12 to 14 ins. square, and in thickness from $\frac{1}{32}$ in. to over 1 in.; and even larger sizes are often made.

In its physical properties carbon varies greatly, the variation depending upon its composition and treatment in the process of manufacture. The hardness may be from that of chalk to that of crockery, and its specific gravity may vary to about the same extent. It is quite brittle, and this property is retained through all its stages of hardness. The tensile strength and resistance to crushing increase with the hardness.

For cutting carbon the emery wheel is generally employed; it can be drilled or cut in the lathe with steel tools, but its effect is to wear them away very rapidly; even diamonds can be used as cutting tools but a short time. On the hardest specimens these operations are performed with difficulty even with the best of tools.

As applied to electrical engineering, the most important and interesting use of carbon is in the arc lamp; here we find phenomena that are wonderful even in the light of the most advanced science. If two $\frac{1}{2}$-in. carbon pencils be placed with their points in contact, and are included in an electric circuit having a current of 10 ampères, a slight amount of heat will be developed in the body of the pencils, which will be greatest at the point of contact; if, while the current is still passing, the pencils be separated a few millimeters, an arc of great luminosity and heat will be formed. If the poles of a voltmeter be connected with the pencils, the voltage due to the resistance of the arc will be seen to vary directly as its length, or nearly so; at about 20 volts the arc will be scarcely visible, and will increase in brilliancy and heat as the points are separated until the voltage reaches about 50, when the light will appear to be the most brilliant. At a point somewhere above this voltage, possibly 70 or higher, the arc will go out with a snap.

In the above case, if the current be maintained constant, of course the watts required will vary as the voltage, and this variation of the total watts is employed by all makers of arc lamps as a means of moving the feeding mechanism. This, in some lamps, may be so delicately adjusted as to move the carbons toward each other when the distance between the points has increased an amount corresponding to 1 volt, while many lamps require an increment of 5 volts to cause the feeding device to respond.

One of the most notable points in regard to the burning of the carbon arc, is that the temperature in the positive carbon rises much

higher than in the negative. It is noticed that when we extinguish the arc by turning off the current, the point of the positive carbon remains incandescent after the negative point has become black ; the intensely heated crater formed on the positive carbon radiates far more light than the incandescent point which is formed at the end of the negative. The consumption of the positive is about twice as great as that of the negative when burned in the air ; if burned in a vacuum, then the positive only is consumed. These facts seem to indicate that the larger part of the energy of the current is expended upon the positive carbon. A large part of the energy expended upon the arc is doubtless used in maintaining a counter electro-motive force, and another portion is absorbed in the conversion of solid carbon into vapor.

The arc may be colored by the introduction into the carbon of almost any foreign substance, and the color is characteristic of the substance employed, as in the case of the Bunsen flame; and as there are but few substances which are not volatile in the electric arc, the range of color is very large. The intensity of temperature is, without question, highest in the center or inner portion of the flame and lowest toward the outer circumference ; for this reason the vapors of substances arrange themselves in concentric envelopes—those which volatilize at the highest temperature taking positions nearest the center, those which volatilize at the lowest temperature becoming the outer envelope.

The carbon flame affords one of the best subjects for spectrum analysis; it is therefore of great value for this purpose, and by its use the field of the spectroscope has been greatly enlarged.

It is perhaps important to note that, aside from the color effect of foreign substances in the carbon pencil, there is in most cases a reduction of the light and generally a lengthening of the arc ; this may be accounted for on the supposition that foreign substances usually volatilize at temperatures lower than carbon and hence supply vapors which radiate less light, and, volatilizing more rapidly, the quantity of the vapor is increased and a corresponding reduction of voltage may also be noted. If the foreign substances are not homogeneously incorporated with the carbon, the arc will be unsteady and the light will be unsatisfactory.

In the burning of arc-lamp carbons, there is always a quantity of carbon dust that falls from the burning points ; this is not a product

of combustion, but particles of carbon, which are detached and thrown off from the highly heated points by calcination. Many attempts have been made by inventors to reduce or prevent the loss of life of carbons due to this cause. Some degree of success has been attained by introducing into the carbon ingredients which, fusing at a comparatively high temperature, become slag and mix with the detached particles and prevent them from falling off; and retaining them until they are consumed, the life of the carbon is prolonged to a very marked degree.

The hissing sound so frequently observed in the arc-light carbons is a matter of importance. There seems to be a strong current of air and vapor moving between the highly heated points; when this current impinges in a certain manner against the point toward which it flows, hissing will be the result. To illustrate: if a jet of air be blown from a small tube, at high velocity, against a solid substance, a hissing sound will or will not be produced, depending upon the velocity of the air, the nearness of the solid and its configuration.

Many experimenters have endeavored to obtain a quiet, steady arc by the introduction into the carbon of foreign matter, which, by producing vapor more easily than carbon, will so modify the conditions as to prevent hissing; and, with a view of holding the arc in the center, a core is used. This core is simply a center, which may be $\frac{1}{16}$ in. or more in diameter, of a material that is different from the body of the pencil and contains more or less of the foreign matter.

Some of the most quiet and steady-burning carbons that are in use have been obtained by the use of foreign matter and a core. Carbons are also made with hollow centers, through which solutions of salts are simply poured, a sufficient quantity being left therein to produce the desired result.

As early as 1867 M. Carré coated carbons with metals, such as zinc and tin; and about the same time Mr. Joseph Van Malderon experimented with carbons electroplated with copper. Carbons have, therefore, been electroplated almost from their first introduction, and copper has been the metal used. The only reason the writer has seen assigned for this use of copper is that it reduces the resistance, conveying the current to the end of the pencil with but little loss of energy. The life of the carbon is increased by coating with copper from 8 to 10 per cent.

The total resistance of an uncoated pair of ½-in. carbons, in a newly trimmed lamp, is about .20 ohm, while the total resistance of the lighted lamp is about 5 ohms. It is evident, therefore, that the resistance of the carbons is about 4% of the total resistance of the lighted lamp. The resistance of the lamp coils may be 2 per cent. The decrease of resistance due to copper coating will not account for the increase of the life; this is due, in the writer's opinion, to the fact that the copper tends to support and retain the particles of carbon that are detached from the points by calcination; to some extent, also, the fused copper forms in liquid beads, and, by absorbing the calcined carbon dust, tends to prevent its loss.

A comparatively new use for carbon is found in the carbon brush for dynamos and motors; here carbon is substituted for the copper brush, and hence retains the name, which appears like a misnomer. Carbon brushes reduce the cutting of the commutator and the sparking to almost nothing. The same commutator may be used for years with carbon brushes which, if copper were used, would be worn out in a few months. The quality of the carbon brush is of great importance; it must be of fine texture, sufficiently hard, and should act in some degree as a dry lubricant, and it should not give a squeaking noise. These are points that can be provided for by the manufacturer. Much difficulty is sometimes experienced by heating. This, of course, is a question of conductivity, and can usually be remedied by making the brush larger, or by coating it with copper, or by doing both.

The telephone is indebted for a large measure of its great success to artificial carbon. Here its value depends upon the principle that an increase of pressure produces a decrease of resistance. The writer is inclined to think, with Mr. S. P. Thompson and others, that the increase of pressure simply makes a more perfect contact. As the resistance of carbon is higher than that of metals, it is, in some cases, an excellent material for this purpose, and especially where moderate resistance is required.

Among the advantages of carbon for electrical resistances, we may note the fact that it can be heated almost to a red heat and held at this temperature, without undergoing any change whatever; and, being practicably infusible, it will stand for a short time very high temperatures, even in the atmosphere, without suffering any deterioration. If held long at a red heat, however, in the air, it will calcine and

sometimes oxidize. Carbon has also the remarkable property of showing a reduction of resistance as the temperature rises. At high temperatures this is very marked; for example: the decrease in resistance of an incandescent lamp filament at a white heat may be one-third of its resistance when cold. At temperatures below a red heat, however, the change of resistance is of comparatively little importance.

Some of the difficulties that attend its use as a resistance material are as follows: the resistance of carbon varies between wide limits; two carbon pencils $\frac{1}{2}$ in. in diameter and 9 ins. in length could be selected, of which one would have a resistance of .20 ohm and the other .07 ohm. The forced carbon being more dense is always lower in resistance than the moulded, other conditions being the same. The resistance, however, may be largely controlled by variations in the manufacture.

The connection between carbon and a metal conductor often becomes a troublesome point, especially if high temperatures are to be used. For low temperatures the carbon may be electroplated with copper and the metal conductor may then be soldered; but for high temperatures the connection must be made by some form of clamping device.

Carbon is not used as a resistance where calibrated resistances are required, owing to the difficulty of predetermining its exact resistance. For resistance purposes, carbon is used in the form of pencils as small as $\frac{1}{8}$ in. in diameter; larger sizes are also used; it has also been used in the granular form and as a powder.

As a contact piece, where contacts must be made and broken frequently, carbon has a great advantage in many places over metals; and frequently, where metals are used in switches for contacts for large currents, carbon blocks are successfully used as a last point of contact. In such places as these last mentioned, carbon often gives a long arc, but even where one pole is metal, instead of burning the metal the current seems to expend its energy on the carbon, which suffers but little and is renewable.

Carbon is almost universally used in primary open-circuit batteries for the positive pole, and for this purpose it is made in the form of cylinders or plates. It is not acted upon at ordinary temperatures by any acid or other liquid known to chemistry, and in batteries it is easily depolarized. Carbon is also used, to a limited extent, for crucibles;

and, when mixed with clay, stands very high heats without oxidization.

It is remarkable that while carbon is made in a variety of forms, its uses are almost entirely confined to electrical engineering; and as we note the rapid advancement of this new department of scientific work, we may also note, as one of the changes it has brought to our century, this new industry—the manufacture of carbon.

A slight idea of its growing magnitude in the United States may be gained from the fact that it claims an investment of over $1 500 000.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

630.

(Vol. XXIX.—September, 1893.)

THE GUADALAJARA ELECTRIC-LIGHT INSTALLATION, UTILIZING THE FAMOUS JUANACATLÁN WATER-FALLS, 28 KM. DISTANT FROM GUADALAJARA.

By RAFAEL M. DE AROZARENA, Mechanical Engineer, Member of the American Society of Mechanical Engineers, and of the Association of Engineers and Architects of Mexico.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Among the industrial enterprises taken up in Mexico by local capital, the plant for the supply of the electric light and power in the City of Guadalajara, Jalisco, is one of the most notable, not merely because of its magnitude with respect to the investment required, but also because the project necessitated the use of novel and special machinery, the source of supply being located 17 miles from the base of demand.

The problem was to install at the falls of Juanacatlán (the Niagara of Mexico) a hydraulic and electric plant which should be capable of

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

supplying in the city of Guadalajara—distant 17 miles—sufficient electric energy to operate some 950 H. P. in the form of light, divided up as follows: Seven thousand five hundred incandescent lights of 16 candle-power each, and 200 arc lights of 2 000 candle-power each.

After careful consideration and study, the plans were projected and machinery ordered from the following well-known houses: The electric machinery and material from the Thomson-Houston International Electric Company, of Boston, Mass.; the turbines and piping from James Leffel & Company, of Springfield, O.; the valves from the Ludlow Valve Manufacturing Company; the countershaft, clutches, pullies and bearings from the Hill Clutch Company, of Cleveland, O.; and the iron poles for carrying the wire on the main line from the falls to the city—a distance of 17 miles—as well as for the wires in the city, from the Reading Iron Company, of Reading, Pa.

The falls of Juanacatlán are on the Grande River, and situated some 17 miles (28 km.) southeast from the city of Guadalajara. The whole volume of the river falls at this point some 58 ft. in a perpendicular line, with the shores above the falls sloping gently to the stream. Below the falls, the shores on both sides slope almost at an angle of 45°, leaving but little room at the bottom upon which a building could be erected, for which reason the building was projected of three stories, as shown by the section of Plate No. 1.

The work above the falls was simple and of easy execution, for, the river being very wide at this point, its depth is small, and a masonry wall some 3 ft. high was built, running across the river for two-thirds of its width and at an angle of 45° to the line of the falls, the object of which was to carry the greater part of the water in the river to a given point on its left bank directly at the falls; then a raceway was formed 14 ft. high by 14 ft. wide, from which the 7-ft. diameter conduit pipe carried the water down to the turbines. This conduit pipe is made of wrought-iron sheets ¼ in. diameter, riveted together, no flanges being used. At the head of the pipe is located a vent pipe, to protect the pipe from collapsing when the wooden gate which is located at its entrance is closed. The pipe, to conform to the nature of the fall at this point, has two elbows of 90° and one of 45°, from which on a horizontal line it connects the three turbines together, reducing its diameter from 7 to 6 ft. between the first and second turbine, and from 6 to 5 ft. between the second and third tur-

bine. Directly in line with the piping are located the three horizontal double Leffel turbines, and between the turbines and the conduit pipe in the connecting pipes, which are 4 ft. 6 in. diameter each, are located Ludlow straightway gate valves, which are opened and shut by geared hand wheels, thereby permitting the water to be closed off from each or any of the turbines without having to stop the others.

The turbines located on the first floor of the building are horizontal double wheels, placed in one case; both wheels are connected directly on to the same shaft, which extends out from the case on both sides, and has at each end a sheave pulley for transmitting the power. Each turbine is 20 ins. diameter, and has its independent draft tube; and as the river is known to rise in the rainy season from 1 to 2 m., the turbines were placed 16 ft. above the bed of the river, with draft tubes, all 10 ft. long, discharging into a well 4 ft. deep (which is the average depth of the river in the dry season), making the distance from the center of the turbines to the surface of constant water in the tailrace exactly 12 ft. This mode of setting turbines with draft tubes has given the writer excellent results here in Mexico.

The power of each set of turbines is 550 H. P., making a total of 1 650 H. P. The power is transmitted from the turbines to a countershaft placed in the second floor of the building. A rope driver is used, of endless manilla, plumbago, tallow-laid rope, 1 in. diameter, using an idler pulley on a stress car, with weight. Each pulley has 15 grooves to receive the 15 strands of rope.

The 42-in. diameter pulleys on the turbines connect with clutch pulleys on the countershaft of 84 ins. diameter, giving a speed of 6 594 ft. per minute to the rope. This driver, when the speed does not exceed 7 500 ft. per minute, by using sheaves at least 40 times the diameter of the rope, the writer has found to be very satisfactory, and on account of its duration much cheaper than belt drivers, especially for damp places.

In Orizaba, over two years ago, the writer used this driver for transmitting 188 H. P., for electric-light work; the rope, which to-day shows no signs of wear, is the same one which has been used from the start, and the plant has run on an average 11 hours every night, without any interruption. Great care must be taken, however, not to put too much weight on the stress car which carries the idler pulley.

Arc-Lighting Dynamos.—For furnishing current to operate the arc

lights, the familiar Thomson-Houston "M. D." dynamos were employed. They have capacity each for 50 arc lights of 2 000 candle-power, or, in other words, a rated output of 25 kilowatts. The current strength is 10 ampères and consequently the maximum voltage 2 500.

The dynamos weigh 3 tons each, require floor space of about 15 sq. ft., a belt speed of 3 863 ft. per minute, with a consumption of nearly 50 H. P. under full load. Four such dynamos are in use, operated two in "series" to avoid multiplicity of wire. Thus, for a total capacity of 200 lights, only two circuits leave the generating station. Each dynamo is supplied with the usual ingenious and efficient "automatic regulator and controller," without which it would be well-nigh impossible to fulfill the condition. With such, however, lamps may be lighted or extinguished without the necessity of paying attention to the dynamo.

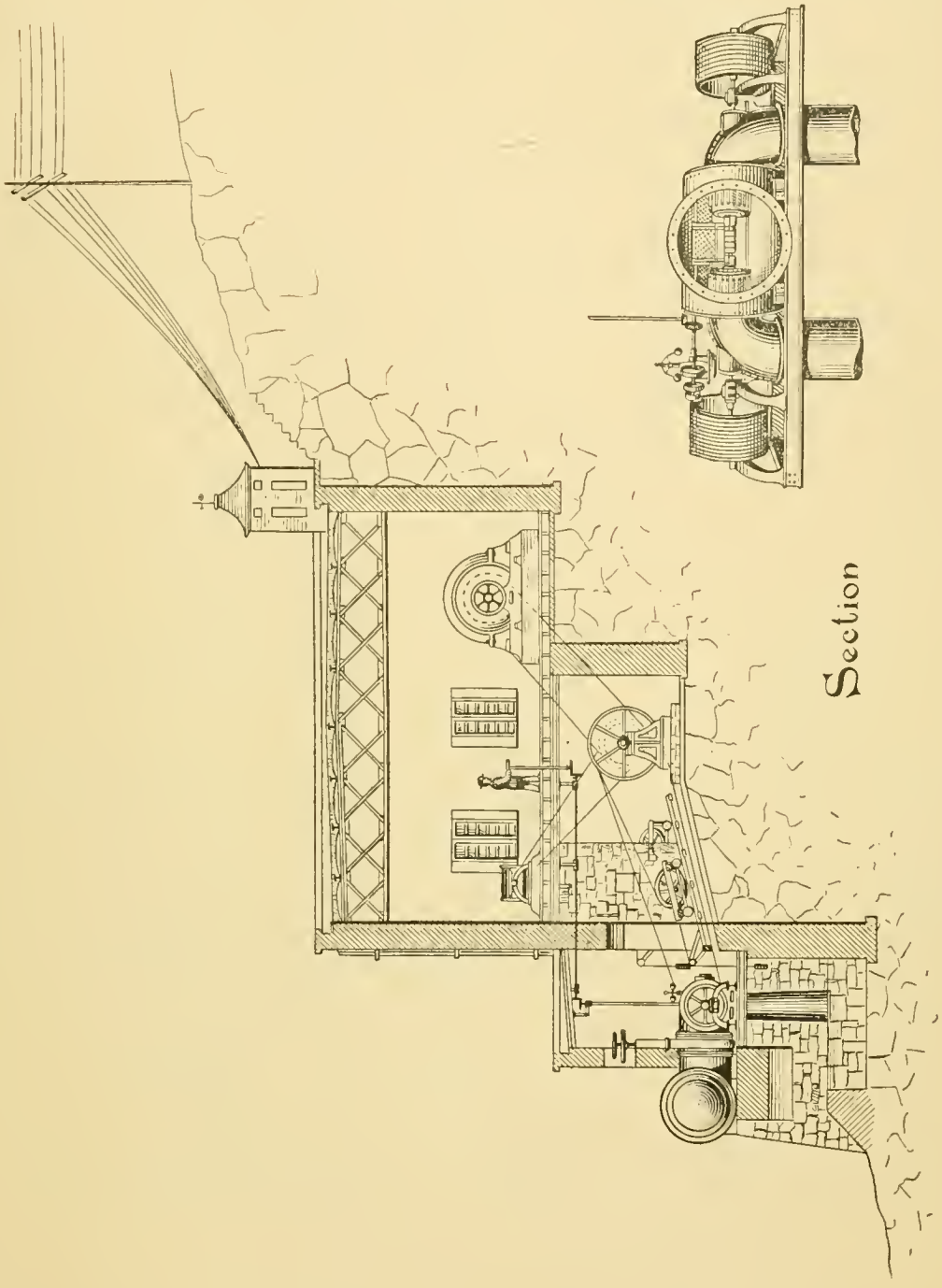
Arc Circuits.—The current is conveyed from the dynamos by means of highly insulated copper wires to a slate switch board arranged for any desired combination of machines; from here through current indicators to the lightning arrestors, from which the wires are led to the pole line. The pressure utilized being rather above the safe limit, the insulation of the circuit is augmented by fastening the wires upon oil insulators, mounted upon wooden cross arms. The construction of these insulators is such that leakage is practically prevented, as, in order to escape by leakage, it would be necessary for the electricity not only to overcome the wire insulation, but also to pass through two strata of oil, the insulating qualities of which are well known.

In the city of Guadalajara these circuits are led to a central distributing station, in which is placed a duplicate plant of lightning arrestors, switch boards and testing instruments. It is from this station that the lights are directly controlled.

Arc Lamps.—Standard double carbon arc lamps are used throughout the city. They are suspended from steel cables stretched from corner to corner, supported by house structures arranged with pulleys and cables so that the renewal of carbons may be readily attended to.

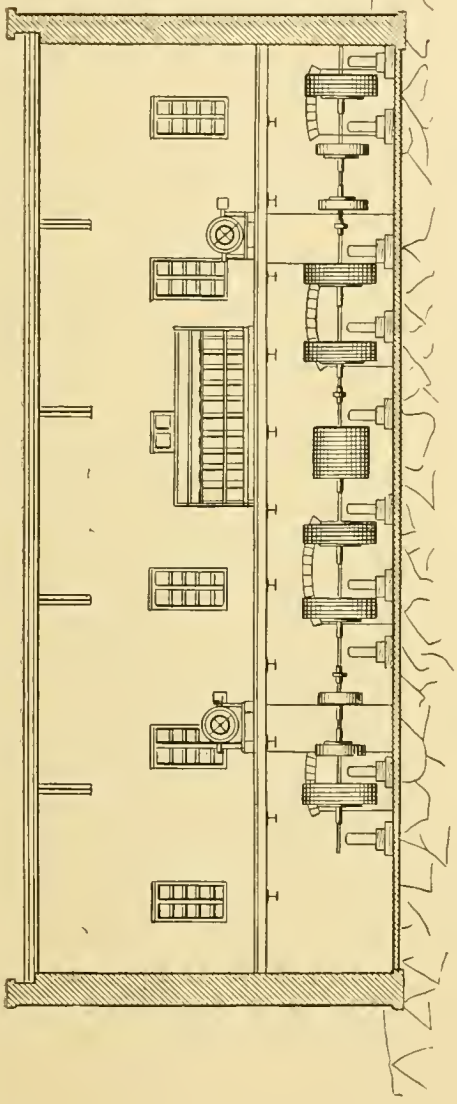
Incandescent Dynamos.—As but one dynamo was desired for this installation, one of special construction was supplied. It is of the alternating current type, has 40 pole pieces, and yields approximately 350 ampères at 1 000 volts, or, say, 350 kilowatts.

VOL. XXIX, No. 630.
TRANS. AM. SCC. CIV. ENGRS.
DE AROZARENA ON ELECTRIC-LIGHT INSTALLATION.
PLATE I.

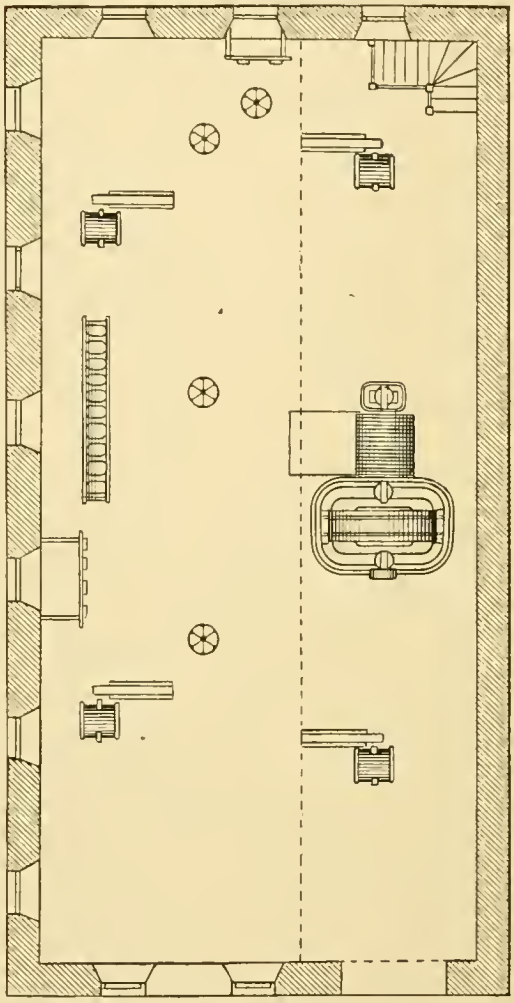


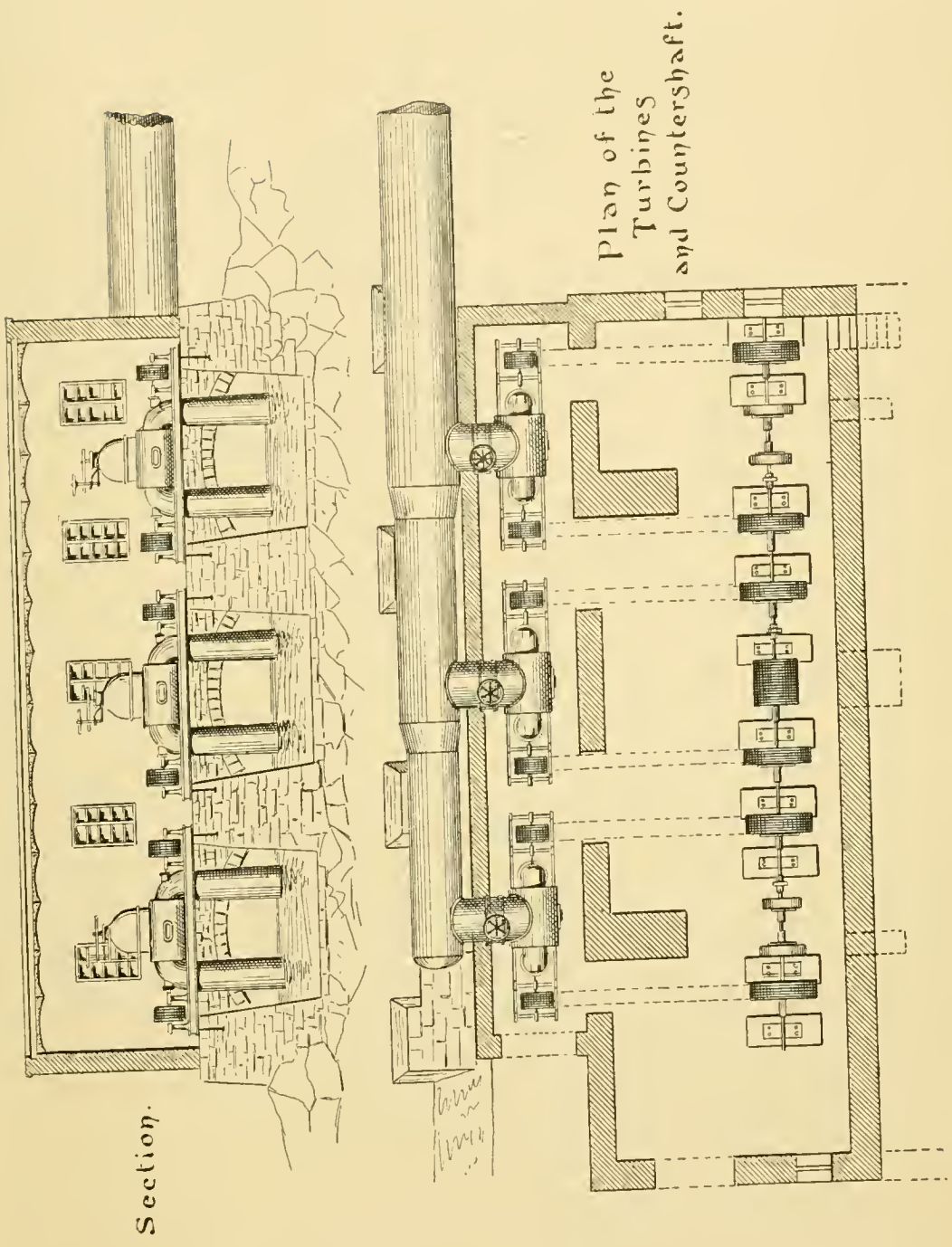
VOL. XXIX, No. 630.
TRANS. AM. SOC. CIV. ENGRS.
DE AROZARENA ON ELECTRIC-LIGHT INSTALLATION.
PLATE II.

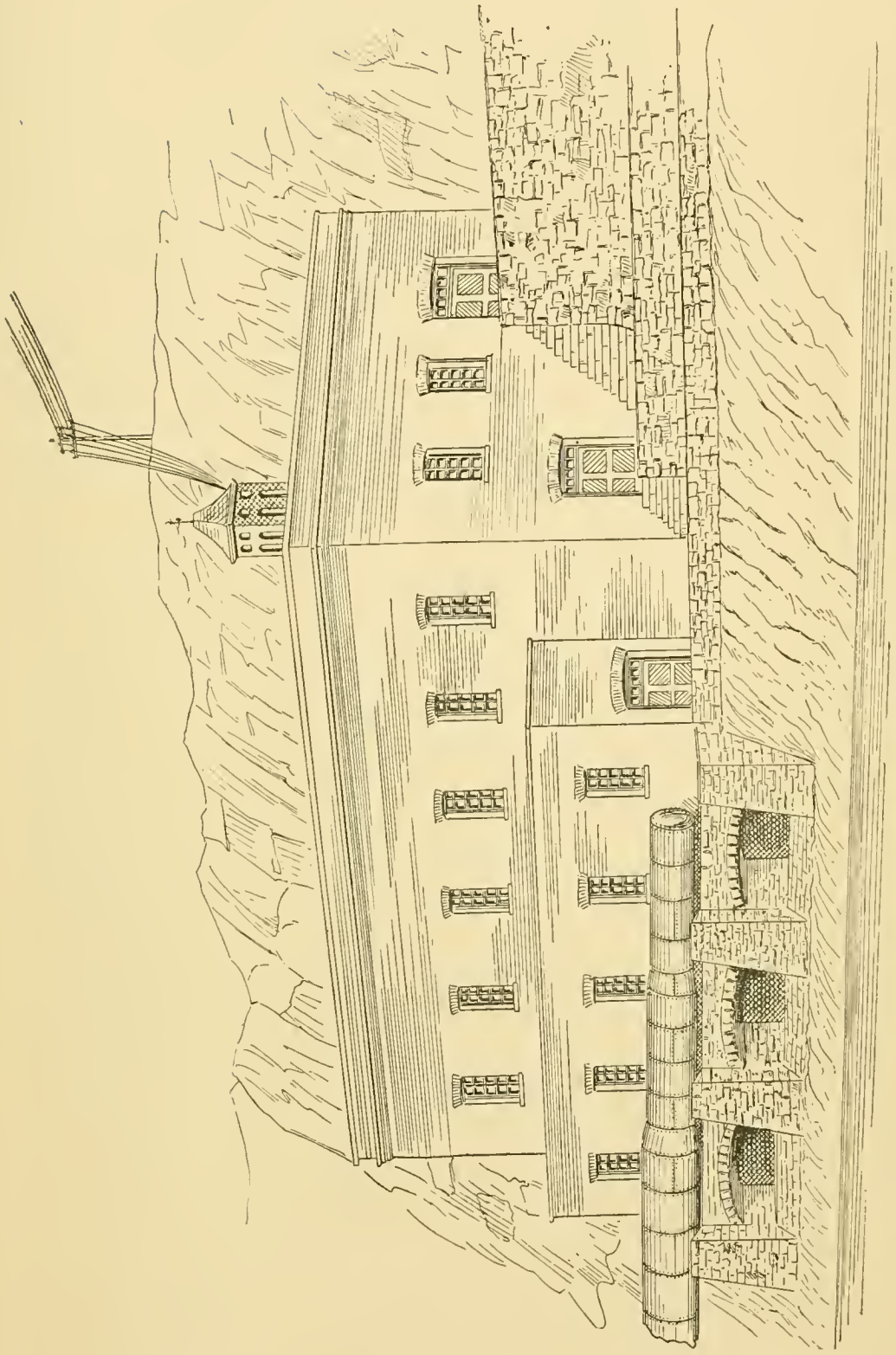
Longitudinal Section



Section




Plan of the Turbines and Countershaft.
Section.



The dynamo weighs between 30 and 40 tons, requires a floor space of 216 sq. ft. and a belt speed of 5 024 ft. per minute, consuming, under full load, some 750 H. P. The armature is run at the low speed of but 300 revolutions per minute, and the shaft, which is 9 ins. in diameter, is furnished with a 60-in. diameter pulley, having 28 grooves for 1¼-in. rope, as this dynamo is driven from the countershaft with a rope driver the same as between the turbines and the countershaft. The 40 pole pieces forming the field magnets are excited by means of a separate exciter, known as "D–5," and having an output of 5 kilowatts at 125 volts.

Various indicating instruments are installed, enabling the operator to tell at a glance what load is upon either machine and at what pressure the dynamos are operating. To convey with moderate loss so great a current as 350 ampères over a distance of 17 miles would require a copper wire having a sectional area of about 4 sq. ins. Such a conductor could not be used, for practical reasons, to say nothing of the expense, which would be itself prohibitive. As the proper section of copper wire varies directly with the current it is necessary to carry, it is obvious that, in order to transmit such power over a wire of moderate size, the quantity of current must be reduced. Without changing the quantity of wire this may be done by increasing the voltage, which, accordingly, was raised to a maximum of 5 000, thus reducing the current to about 70 ampères, and the size of the wire to one having a sectional area of .1662 in.

Step-Up Transformers.—To so increase the voltage from 1 000 to 5 000, a bank of 10 step-up transformers was installed. These are built upon the lines of the type "F" oil transformer manufactured by the General Electric Company. They transform the energy of the dynamo at an efficiency of about 98%, delivering to the line, therefore, 98% of the energy supplied them and at five times the pressure. The transformers are so designed as to be filled with oil, the insulating qualities of which are very high, thereby increasing the insulation resistance of the transformer, rendering it less subject to damage from lightning discharges, and, indeed, restoring the insulation, should it be destroyed by means of a stroke of lightning. The transformers are banked or operated in multiple. They have a capacity of 30 kilowatts each; weigh approximately 1 300 lbs., each requiring 12 cu. ft. of space. They are protected by a simple but effective system of circuit

breakers and fuse connections, and the current passing from them is carried through a special lightning arrestor designed to protect circuits of extraordinary high potential.

Main Circuit.—The cross arms, pins and insulators used in connection with the alternating circuit are precisely the same as those described under the heading "Arc Circuits."

Step-Down Transformers.—The high potential incandescent line carried to the central station in the city of Guadalajara is passed through lightning arrestors and safety devices, as described above, to the bank of step-down transformers, which reduces the pressure to 1 000 volts, at which potential it is carried through the streets of Guadalajara as in ordinary installations. In the Guadalajara Central Station switch boards are installed, enabling any combination of lights and circuits to be made, without attention to the dynamos at the point of generation. The number of lights in operation, the physical conditions of the circuits, and indeed the conditions of the dynamos at the generating station, can all be determined in Guadalajara. Telephonic communication is established between the two stations, enabling those in charge to give their directions promptly.

As a further protection against lightning, which in the State of Jalisco is very severe, iron poles have been used, each surmounted by a pointed lightning arrestor rising some 3 ft. above the top of the pole, or, say, 5 ft. from the highest current conveying wire. These arrestors are, of course, mechanically connected to the iron poles, besides which they are joined to each other by means of an iron wire. This is considered the most effective protection possible, as it produces an artificial earth above the wires conveying the electrical current.

NOTE.—The president of the company, Mr. José María Bermejillo, is an old resident in the country and very well known throughout Mexico on account of his enterprising character. This gentleman owns the Juanacatlán Falls, and has long been endeavoring to work up this company.

The writer wishes to express his sincere gratitude to Mr. Samuel C. Peck, of the Thomson-Houston International Electric Company, and to Messrs. James Leffel & Company, for having so willingly assisted him in compiling all the necessary information towards the construction of this important work.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

631.

(Vol. XXIX.—September, 1893.)

THE RELATIVE MERITS OF WORKING HOISTING MACHINERY BY STEAM, WATER AND ELECTRICITY.

By GEORGE A. GOODWIN, Senior Vice-Pres. of the Society of Engineers; Assoc. M. Inst. Civil Engineers; Whitworth Scholar.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In approaching this subject, one should do so with an unbiased mind; unfortunately many people who have a predilection for one system, or who, perhaps, may be the parent of a particular method of utilizing power, are too prone to conclude that that system is best suited for each and every purpose. The author cannot urge too strongly the fact that each installation should be specially and individually considered. The advantages and disadvantages that would accrue from the application of each should be considered, with the result of selecting the one which shows least objections, for no doubt none would be perfect.

Since the early days when the ordinary wheel and axle windlasses

NOTE —Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

were used for all kinds of lifting and hoisting, vast strides have been made, first, in the application of steam, then of hydraulic power, and lastly of electricity. All of these powers can, without doubt, be employed for working all the known hoisting and lifting machines, such as traveling and fixed cranes, travelers, Goliaths, winding engines, hoists and lifts, but not all with equally useful and economical effects. The questions that arise, and which concern all engineers who have to select and decide on a system of power for application to a certain purpose, are:

First.—Which system is most economical to work?

Second.—Which system entails the least initial outlay?

Third.—Which system has the fewest disadvantages?

The author would here remark that he does not profess to be able to say anything novel about hoisting machinery *per se* that is not already familiar. He will confine his remarks to comments on the suitability of each system to the various purposes to which they can be applied, their advantages and disadvantages, investigating the *pros* and *cons* of each, and, by giving some figures on the costs of installation and working, he hopes, by inviting friendly criticism combined with the statements of the valuable experience gained by other engineers on this side of the Atlantic, to put on record reliable data which he trusts may be of value to the members of the profession.

Before entering into the details indicated, the following postulates should be conceded.

First.—That steam-worked machines are supplied with steam drawn from a center or distributing boiler or boilers, or that each machine is supplied from a self-contained boiler.

Second.—That where hydraulic power is used, the water is supplied from a central pumping station and distributing plant.

Third.—That where electricity is used, the current is supplied, as in the hydraulic system, from a generating plant from a central station; for, obviously, if the hydraulic or electric power were generated by an engine self contained on the machine, the conversion of the energy in the steam into hydraulic or electric energy, to be after re-converted into mechanical power, would entail considerable loss in useful effect as compared with driving direct, unless some system of storage were introduced.

Steam.—To obtain the full advantage of steam, when used as the

motive power, it is necessary, primarily, that all the machines so driven should be supplied from one or more batteries of boilers and should be regularly at work, in order that the average demand for steam should bear a high proportion to the maximum drawn off and for which the boilers are designed, so that the firing and evaporation may be as nearly as possible constant. If this condition of working does not exist, a considerable loss of efficiency must result.

By reason of the difficulty of regulating the supply and the combustion of the fuel, which naturally cannot be quickly adjusted to accord with the varying requirements, particularly if mechanical stokers are used (which are so necessary to economical firing), it follows that at times of small demand for power there will be a relative excess of steam formed going to waste through the safety valve, while during large and sudden demands there will be a deficiency; and in case of the former, all the working expenses, as well as coal and water, go on uninterruptedly, thus reducing the efficiency and raising the cost of working abnormally high.

Again, there must always be a slight continual loss by radiation along the steam pipes and boilers however well protected by some of the many non-conducting compositions, and which increases proportionally when the demand for steam is low.

One method of lessening the cost of working is by keeping the boiler output constant. The overcoming of the difficulties of storing heat energy as it is formed in excess of the supply drawn has recently been brought forward by Mr. D. Halpin, of London, and referred to by Professor G. Forbes in his paper read before the St. Louis National Electric Light Association on March 1st, 1893.

It is well known that when a large plant is at work, the individual units being spread over an extended area, the demand for power must fluctuate, and that the minimum and maximum loads differ very greatly from each other, the maximum load sometimes reaching from three to four times the average load. To cope with this fluctuation, it is necessary to supply motive power capable of handling the maximum demand when it arises, and which is consequently three to four times the capacity that it need be if the power were required at an even rate and of the same total amount.

The system may be briefly described as follows:

A sufficient number of ordinary boilers are fitted up and worked

night and day, and are of such a capacity that the steam generated by them during that period will suffice for a day's work; to these are attached what are styled "Thermal Storage Reservoirs," which are proposed to be of a vertical cylindrical form, and the live steam taken from them direct to the engines.

Instead of the usual number of ordinary boilers, some of which are, during nearly all the working hours, doing duty at an uneconomical load, while others have to be kept fired up in a state of readiness, that are required for supplying sufficient steam to cope, not only with the average, but the maximum, demand, Mr. Halpin proposes to reduce their number to such an extent that those left shall be constantly at work at their most economical load during the 24 hours, that is to say, that their total capacity per day (of 24 hours) shall be slightly in excess of the total demand for steam during the hours of working.

A sufficient number of thermal storage reservoirs, which are to be vertical cylinders, egg-ended, 30 x 8 ft., are connected to the reduced number of generating boilers, and nearly full of water, sufficient space being left at the tops to allow of ample steam-generating space, the boilers themselves being full. A necessary condition to the maintenance of an efficient storage, and to keep this plant as small as possible, is that the pressure in the generating boilers and the receivers should be considerably higher than that at which the engines are to work, the pressures proposed being 250 and 130 lbs., respectively. The steam supplied is drawn off from a steam receiver connecting all the reservoirs, and passes through a reducing valve. The action is then as follow: The water in the generating boilers is heated and circulated round the system up to such a temperature as accords with 250 lbs. pressure (406° Fahr.). The engines then, as already mentioned, are supplied direct from the reservoirs, and at times of small demand, below the average, heat is stored in the reservoirs; while at times of large demand, above the average, steam can be drawn away from the reservoirs at any rate desired, which, as it is drawn off, relieves the pressure to which the heated stored water is subjected; the latter concurrently flashes into steam and keeps up the supply. It is proposed to keep the level of the water in the reservoirs as constant as possible, but during periods of heavy loads and large demand it is allowed to fall, being made up again during periods of small demand. The feed water is pumped into the reservoirs where all

sediment is deposited, as hot as possible; by this means the boilers always work on clean water, which greatly enhances their efficiency and life.

The practical efficiency of this system has yet to be proved, the great question being the regulating and insuring of proper circulation of water, which, when the number of storage reservoirs containing it are greater than the number of the generating boilers supplying them, causes such an increase in the difficulties that on this particular point the whole success must depend. In other respects, one can venture to prophesy satisfactory results.

When hoisting machinery, such as isolated cranes, lifts, etc., is used, it is necessary to economy that they should be constantly at work, or else a considerable loss must take place in the combustion of fuel during the periods of light load or small demands already alluded to.

Where a large plant, however, such as is generally used at all docks of importance, and where a large proportion of the cranes could be relied upon to be working simultaneously, steam can be economically supplied from a central battery if other and disturbing conditions do not arise, such as :

(*a*) The difficulty of connecting the cranes to the main steam pipes, at the different points required for service, where such cranes are to be movable along, for instance, the side of a quay.

(*b*) Risks of sudden and complete stoppage of the whole of the plant, and danger to human life in case of the bursting of a main.

(*c*) The loss entailed by reason of the expense and difficulty of returning the exhaust steam to the boilers, or else allowing it to escape into the atmosphere.

The author is aware that this question of supplying steam over an extended area has been successfully accomplished by the steam supply of New York; but here, as far as he knows, the spent steam and condensed water is caused to flow back again to the generating station, where it is no doubt easily returned to the boilers. Where, however, the steam supply is to be used for motive-power purposes, it would be necessary to condense the steam at the generating station on its return, so as not to throw a back pressure on the consumer's engines,.

thus necessitating increased plant and working expenses. For driving shop or yard travelers, this system of central steam supply is not applicable, on account of the difficulties referred to in the way of connections of machines to steam pipes while allowing for their traveling.

With regard to efficiency, it appears from the comparison of different steam cranes and hoisting machines that about 1.1 to 1.4 lbs. of steam, on the average, are utilized in the cylinders (at 60 lbs. boiler pressure) in small and large cranes, respectively, for every horse-power of work done on the weight lifted, and taking the evaporation of water per pound of coal in the case of a central supply battery at 9 lbs. and in self-contained power machines as about 7 lbs., the figures work out as follows: In plant supplied from central battery 7.33 lbs. of coal are required per hour per horse-power done on the weight, and in self-contained machines, 9.4 pounds.

To test the actual cost on a large practical scale, the author, through the kindness of some friends at an important coal station in London, has been enabled by a three-days' trial to determine that the cost of lifting coal from the holds of vessels lying alongside on to the wharf to be 1½d. per ton. This includes craneman's wages, cost of cranes (taking their life at 20 years), coal, oil, waste, water and repairs.

For large concrete block-setting machines, generally known as "Titans," or for yard travelers, contractors' cranes, excavators and such tools, machines with self-contained engines and boilers would no doubt prove the most serviceable.

In steam-hoisting machinery there are, necessarily, a large number of working parts, both in the engines and the machines proper, including the various shafts, gears, clutches or cones for putting the different motions in and out of action. These not only give rise to much rattle, wear and tear, but necessitate a heavy amount of upkeep and require the attention of an experienced driver, who also has to attend closely to the boiler firing and feeding, while undivided attention should be given to the work in progress.

Hydraulic Power.—As in the case of steam, to use this power economically it is also necessary that all the plant supplied from one central station should be regularly at work, and that the average demand for power-water should bear a high proportion to the maximum that the plant is designed for; otherwise the losses in fuel, steam and general

working expenses at periods of small demand will exist. These losses, however, can be effectually prevented in certain cases, where, instead of obtaining the pressure-water by passing it through accumulators, circumstances permit the use of a storage reservoir, placed at the required height, to give the desired pressure, and of such a capacity as to contain a supply for at least 24 hours' working. This, neglecting pipe friction, would be 1 613 ft., to give an effective pressure of 700 lbs. per square inch. In this case, under such conditions, the pumping plant would only have to be of sufficient daily capacity as the average required by the working plant spread over the 24 hours.

Where plants, however, take the form of a public service, such as exist in London, Hull, Birmingham, Liverpool, Manchester, and some of the chief cities in Australia, and where, by the multiplicity of uses to which the power is applied, the average demand in such cases becomes fairly constant during known periods, the daily consumption is proportioned somewhat as follows : From 6 to 8 A. M., when the artisan class commence working, warehouses and loading and unloading stations are the chief users ; from 9 to 12, full demand takes place, by the continuance of this class of work plus that required for passenger lifts for offices, etc. ; there is then a lull during the lunch or dinner hour, and from 2 till 5 or 6, when the warehouses close, there is again the full demand. After this another special requirement takes place, in the use of lifts in hotels, clubs, chambers, residential mansions, etc., giving a gradually lowering load until midnight, when the minimum takes place until 6 A.M. And so, by the use of a constant daily diagram, which can be taken and recorded, it becomes possible for the officer in charge of the central station to regulate the firing of the boilers and generation of the steam-power, and thus a fairly good efficiency and economical working of the plant can be obtained even where the water pressure is obtained by passing it through accumulators.

There is no doubt that hydraulic power is peculiarly adapted for all kinds of lifting purposes, the working of presses of all types, and last, but not least, as a means of obtaining powerful jets of water for the extinction of fires.

The action of the water in the hydraulic cylinders, viz., the moving of the rams in a rectilineal direction, renders this power the most direct of all others, as all hoisting machinery has obviously to move

weights straight up and down, and all rotary motion, with the constant reduction in speed and the consequent wear on rapidly moving parts, can be dispensed with. The expression "rapidly moving" is used advisedly, as in almost all cases the prime revolving motor, to be within reasonable proportions, has to be made to work at a relatively high speed. With regard to wear of hydraulic machines, the friction of the rams in the glands is almost infinitesimal; the only parts subject to much work and abrasion are the chains or ropes and the axles of the pulleys over which they pass. This, also, is very small, owing to their slow speed of rotation.

One great disturbing element to the proportioning of the supply of water-power to the work to be done, always more or less exists in hydraulic machinery, and is due to the fact that water is non-compressible and non-expansive, the result being that the same quantity of water is used, whether the load lifted is great or small, and, in the case of hydraulic engines, that there is difficulty in regulating the strokes to the work required to be done.

In this branch of mechanical engineering, however, some success has been arrived at in overcoming these objections.

With regard to lifts, instead of having only one hydraulic ram or jigger for working hoists or suspended lifts, or only one ram or cylinder for the direct-acting lift, several actuating rams are supplied, attached to a common crosshead, and which can either be worked separately, combined, opposed or collectively; and by admitting the water to them in either of the ways just mentioned, it will be seen that any desired power can be obtained, the regulation of the admission of water to any or all of these cylinders being controlled by a supplementary valve called a power-setting valve, in addition to the ordinary starting valve. In this case the attendant has only one starting valve to operate, and on his opening the passage for the water it flows to the cylinders first through the power-setting valve, which latter, being hydraulically pressed forward, keeps on moving to greater and greater powers by giving access to further cylinders, until the lift rising has attained a certain prescribed speed, when the power-setting valve is locked by a pawl worked by a governor, and the lift goes on rising at the correctly proportioned power. When the lift stops, the governor drops, the pawl is released, and the power-setting valve returns to its normal position. Even with this arrangement, however, an exact proportioning of water used, to

work done, is obtained only occasionally, when the weight happens to fit in. Of course, the greater the number of powers, the closer the approximation. The saving effected by this type of hoist or lift is stated to be considerable, and from experiments that have been made between an ordinary jigger lift and a similar one fitted with the differential cylinders, the following figures were obtained :

	Number of days at work.	Number of trips made.	Gallons of water used.	Gallons per trip.	Gallons per passenger.
Ordinary jigger lift.....	275	54 493	393 400	7.22	3.8
New jigger lift	134	27 291	80 700	2.95	1.47

The saving being 57.9 per cent.

In the best designs of hydraulic cranes, when fully loaded and under favorable conditions as to working, the total efficiency is about 60 to 70%, while in direct-acting hoists, that is to say, where only one ram is used, this would rise to about 80%, which represents on the average about 35 lbs. or $3\frac{1}{2}$ galls. of water for every horse-power of work done on the weight lifted. This referred to the consumption of coal at the central station means 4.5 to 5 lbs. per horse-power in weight lifted by the machine.

With regard to cranes or travelers, this principle of varying the power automatically to suit the weight cannot be applied so easily owing to the fact that in this class of machine it never starts in motion with the full load, and a certain amount of movement has to be made to pull up the slack chain or rope, which, in the case of a power-setting valve, would take up a position of a lower power than that required when the power came on. But still the power-setting valve or its substitute could be controlled by hand, the drawback to this being that the operator would in all probability, to save himself trouble, go at once to the highest power.

Referring to hydraulic engines, Mr. A. Rigg, of London, has made a special type known as a revolving engine, in contradistinction to a rotary. By his system the stroke of the pistons in the cylinders are variable and proportioned automatically to the work to be done, the means of doing this being as follows: Three or four pistons are each pivoted equidistant apart to the inside of a ring forming a fly-wheel, while the cylinders in which they work are pivoted round a common

center piece forming a steam chest and valve chamber, their center being capable of lateral movement along a line passing through the center of the fly-wheel and controlled by the governor; from this it will be seen that when the two centers coincide, no relative movement of pistons and cylinders takes place while when displaced, rotation will take place in either direction according to which side of the fly-wheel center they are situated, and the power given out will be proportional to the amount of eccentricity of the cylinder pivot.

This engine does not appear to have been appreciated as its merits deserve, but the author believes that they could do good, economical and valuable work. Several are in daily use working capstans, pumping, and even driving dynamos.

Electricity.—With regard to the use of this still mysterious agent as a motive power for lifting purposes, a fair amount of work has been done of late years, not only by manufacturing electricians, but by mechanical manufacturing engineers particularly, and the author has had the advantage of making tests with some of them. The remarks relating to the necessity of the plant being regularly at work, etc., apply to the use of electricity as well as of steam and water, for although the nature of the dynamo machine is such that the electrical output regulates itself in accordance with the demand, yet the prime mover (the boiler) still gives rise to the difficulties of regulating the fuel and steam generated. The use of secondary batteries gets over this trouble to a great extent, and they are used chiefly in connection with the public electric-light installations, where continuous currents are used; but this, of course, entails an increased initial outlay and about 12 to 18% for depreciation. It appears, so far, that electricity can be applied, and made to work all the known kinds of hoisting machinery; but whether it can ever compete successfully with hydraulic power for general use still remains to be proved. In case of hoisting machinery, such as lifts, there is no doubt that the direct-acting ones are far preferable to those that are electrically worked. In Victoria Mansions, Westminster, London, where the author's offices are situated, there are several hydraulic lifts, and two of them have lately been fitted with an independent accumulator and a set of three-throw pumps, the latter worked by an electric motor. By this means the power-water is, after passing through the cylinders, returned to a tank and used over and over again. The motor is compound wound and drives on to a worm wheel, the

end thrust of the worm shaft being taken by a series of small hard-steel balls working between two hard-steel grooved rings, which system the author first suggested in 1889. The total efficiency of the combined machines, that is to say, the proportion between the horse-power in the water pumped and the horse-power absorbed by the motors is over 50%, and, as far as time has permitted a judgment to be made, the arrangement is giving satisfactory results. The switching on and off of the currents are controlled by the rise and fall of the accumulator weights. This system might find suitable applications in other cases, but would have to be governed by the price of water.

With regard to working cranes or travelers by electricity, both shunt and compound wound motors are used; but the advantages lie chiefly with the latter, as, by using that system of winding, a uniform speed of motor is obtained irrespective of the weight lifted, and again it enables the machine to be stopped and started with the load on. For engineering shops, foundries, setting of concrete blocks, etc., this, of course, is of primary importance, and it will be found best to have separate motors for each movement, such as lifting, traveling and racking, as not only is mechanical gear saved, but it gives the driver easy and undivided control of each movement, leaving his whole attention to be devoted to the object lifted. The mechanical construction of the cranes or travelers can, of course, be made of any type, for instance:

(*a*) When one motor only is used on a traveler it can be made to drive a transverse endless rope passing over and under a series of pulleys and jockey pulleys attached to the crab frame, the said pulleys actuating the various movements either by clutches or open and crossed bands.

(*b*) Or where a separate motor is used to work each movement, if compound wound, would be rigidly attached to one of the spur pinions in connection with the respective gears.

(*c*) Another system would be to attach the motor to the traveling crab, which would save some friction in the way of driving it from one end.

In the case of cranes the motors are generally made to work direct on to a worm, the wheel being on the drum shaft or directly geared to it, or the shaft of the armature may be fitted with a pulley with a slightly hard but compressible face and pressed against the face of another driving pulley geared to the barrel, and so driving by friction.

The most recent electric cranes that have been put up in England are those at Southampton, the frame-work being made by Messrs. Stothert & Pitt, and the electrical portions by Messrs. J. G. Statter & Company. These cranes are very much on the lines of those supplied to the Hamburg docks and manufactured by Messrs. Siemens & Halske, of Berlin, but, as they contain some novel features, the author ventures to describe them somewhat in detail.

The cranes are supported on a traveling gantry having but one vertical end, viz., double frame, carried on four wheels running on two lines of rails. The other end of the gantry terminates horizontally and is supported on an overhead rail on a pair of wheels, but geared with the former. This arrangement admits of the greatest clear space under the cranes, which is necessary in order not to obstruct the passage of locomotives or trucks on the railway which runs under the gantry. Each crane and its frame weighs about 35 tons and is capable of being easily moved along by hand gear, in order to plumb the holds of any vessel it may be handling. The cranes are arranged to lift at 200 ft. per minute and to slew at 400 ft. per minute, and the maximum duty of each crane is 3 tons. The radius of the jibs is 27 ft. 6 ins.

There are two "Statter" motors, the one for lifting, absorbing 200 volts and 220 ampères, making 600 revolutions per minute. It runs continuously and drives a worm and worm wheel. The worm wheel is put into gear with the barrel by means of a "Lindsey" transmitter. Switch gear is provided for stopping, starting and reversing this motor, as required. The slewing motor has a capacity of 50 ampères at 200 volts and makes 1 000 revolutions per minute. It drives by means of a worm and worm wheel, a pinion, gearing into a circular-toothed rack. This motor is stopped, started and reversed, and is always in gear. Suitable slipping clutches are provided between motor and worm gear in both cases. A powerful foot brake is also provided. In addition there is a magnetic brake, which comes into operation and holds the load in case of failure of the supply of current to the crane.

The current is supplied to the cranes in question by the Southampton Electric Light Company, which has laid down a special main from its station to the switch-house at the head of the quay. From this point the crane mains are carried, and consist at present of copper of .25 sq. in. section, capable of extension to 1.25 sq. ins. These are run in a concrete culvert down part of the quay and in a wooden culvert

pitched inside and outside, underneath the timber framing of the quay. At the cranes these mains deliver the current through insulated cable ends to two overhead conductors of silicon-bronze wire. Two clamping blocks are arranged under the gantry to each crane, one to take the positive and the other the negative line. These are clamped by a screw and hand wheel, combined with a stop gear which locks the wheels of the crane gantry when the leads are clamped, and obliges the driver to unclamp his conductor before attempting to move the crane. When the conductors are unclamped, the current is supplied to the crane by the dead weight of the conductors resting in the lower half of the clamps. The current is led from these clamping blocks in a special heavy grooved hard-wood channel to the center pivot of the crane. This pivot is of steel 6 ins. in diameter, bored with a 2-in. hole through which the leads pass. On the head of the crane pin a pair of collector pins are fixed, and from them the current is led to the switchboard. The switchboard fixed in the cabin contains the ampère meter, main switches and fuses for lifting and slewing motors, together with switches for six lamps which are employed to light the crane cabin and to throw light upon the loads. The lamps for the latter duty are fixed in a reflector similar to the system of reflector used in the Naval and Mercantile Marine. Each reflector is attached to the jib. From this switchboard, the current for the lifting and slewing motors is led to special lever switches which grade the supply of current and consequently the torque and speed of the motors. The working surfaces of the switches are built of a special commutator metal insulated by mica. The switches combine in one a regulating and reversing switch. With the lever vertical, the current is off the motor; when forward, it causes in the case of the slewing motor a slew to the left hand, and when backwards, a slew to the right. The slewing may be performed at a very slow speed or at the full 400 ft. per minute, according to the extent to which the lever is pulled over from the vertical. The sparking is taken at two carbon points. There is no sparking on the contact plates. Steel wire rope is used for the lifting. The cranes have been tested by lifting their full load in the presence of the Harbor Committee and their engineer.*

* These cranes weigh 35 tons, and the price is £1 450, while for hydraulic ones of the same capacity on arched platforms to span railway underneath, the weight would be 28 tons and the price, £750.

The tests alluded to by the author were carried out with the view of determining the following :

First.—E. H. P. absorbed by the motor when lifting the chain and hook with no load, so as to determine the friction of the machine.

Second.—E. H. P. absorbed when lifting known weights at known speeds.

Third.—Energy in horse-power put into the weight lifted.

Fourth.—The efficiency of the machine.

Fifth.—E. H. P. absorbed by motor when lowering the load.

Sixth.—E. H. P. absorbed when traveling and lifting.

Seventh.—E. H. P. absorbed when traveling and lowering.

1st Test.—Single 8-H. P. motor, shunt wound, driving a traveler by means of endless gut rope and crossed and open bands, as previously described, 80-volt circuit.

When lifting chain, block and hook, 6 E. H. P.; when lifting 6 tons at 2 ft. a minute, the E. H. P. was 7.6 and the actual horse-power in weight, 1.04; when lifting 1.7 tons at 18¾ ft. a minute, the E. H. P. was 10.5 and the actual horse-power in weight, 2.2; efficiency of machine at 6 tons, 13.5%; efficiency of machine at 1.7 tons, 21 per cent.

2d Test.—Single 8-H. P. motor, shunt wound, working a traveler, driving and traveling by a transverse shaft with compressed paper friction cones at each end, driving two cross shafts by means of being pressed against chilled-iron coned discs, 100–105-volt circuit.

When lifting light, 1.77 E. H. P.; when lifting 7 tons at 7 ft. a minute, 5.75 E. H. P.; energy in horse-power put into weight, 3.32; efficiency of machine, 57.7 per cent.

3d Test.—This was an ordinary hand-power foundry traveler, converted for working electrically, and was driven by one single motor at one end, all the other motions being taken off one transverse shaft.

When lifting light (quick speed), 2.83 E. H. P.; when lifting light (slow speed), 2.4 E. H. P.; when lifting 4 tons at 8.9 ft. a minute, the E. H. P. was 7.73, and actual horse-power in weight, 2.42; when lifting 4 tons at 3.4 ft. a minute the E. H. P. was 5.0 and the actual horse-power in weight, .9; when lifting 9, 13.5 and 18.5 tons at 3 ft. a minute, the E. H. P. were 6.8, 9.6, 9.9, while the actual horse-powers in weight were 2, 3 and 3.7; the efficiency of the machines in the above cases varied from 29.05 to 37.5 per cent.

4th Test.—Southampton cranes.

When lifting light, 4.01 E. H. P.; when lifting .75 ton at 200 ft. a minute, the E. H. P. was 25.16, while the actual horse-power in weight was 10.17; when lifting 1 ton at 200 ft. a minute, the E. H. P. was 31.68, while the actual horse-power in weight was 13.57; when lifting 1.2 tons at 200 ft. a minute, the E. H. P. was 36.86, while the actual horse-power in weight was 16.29; when lifting 1.5 tons at 200 ft. a minute, the E. H. P. was 42.02, while the actual horse-power in weight was 20.35; efficiency of machine when lifting the different weights was 40.4, 42.8, 44.1, 48.4%; when slewing at full speed 1.86 E. H. P. was consumed.

In all the above cases, if the E. H. P. used when lifting light be deducted from the E. H. P. when lifting loads, the net efficiency attributable to doing work is good, viz., 65 and 49% in the first case, 71.7% in the second case, 50% in the third case, and 53% in the last one, thus pointing to the direction in which further efficiencies could be obtained.

From this it will be seen the total efficiency of the machines in tests Nos. 1 and 3 is not high, the worst result being No. 1, the loss of power in this case being evidently due to the necessity for a large amount of gearing when working such a machine from one high-speed motor.

A full table of the above-described tests is given in Appendix No. 1.

Some short time ago the author was called in by the Southampton Harbor Board to make a report on the question of supplying power cranes to their jetties and wharves, either on the steam or hydraulic system, and for the purpose of general comparison in the case of such an installation, he will now give the conclusions arrived at and supplement them by figures relating to an electric plant for doing the same work.

The installation at the outset was to have been only a small one, and comprised the following:

Hydraulic.—One pair of compound condensing engines and pressure pumps; accumulator; two boilers; six 30-cwt. cranes, with 30-ft. jib radius; two 20-cwt. luggage cranes, with 30-ft. jib radius; six large and 10 small capstans; pipes and connections, engine-house and shaft.

Steam.—Cranes, self contained, same as above; capstans, same as above; steam pipes, two capstan boiler-houses.

Electric.—Two pair of compound condensing engines and dynamos; two Lancashire boilers; cranes and capstans, same as above, but fitted with motors; mains.

The total cost of the various systems, including the engine-house and shaft, in the case of hydraulic and electric works, came out as given below; but it does not include the laying of hydraulic mains or the electric conductors, and it must be noted that the steam cranes are assumed to be self contained and not supplied from a battery of boilers:

Hydraulic, with engine-house	£13 561
Steam	11 120
Electric, with engine-house	11 736

The advantages and disadvantages of the several systems are summed up as follows:

Steam Advantages—(*a*) The first cost of installation is less than for hydraulic or electric plants.

(*b*) In the case of the cranes only, as they supply their own motive power, they cannot be affected by the failure of a main or the machinery at the power station, as in hydraulic or electric.

(*c*) The installation can be added to gradually at a less initial cost than with hydraulic or electric plants, where the power station should be sufficiently large for the maximum duty likely to be required from it.

Disadvantages.—(1) It is slow in action compared to hydraulic or electric power, working only at about half the speed.

(2) Each crane generating its own power, they are more costly to work than hydraulic or electric cranes, where one generating station supplies power for the whole plant.

(3) The drivers of the cranes have to be men of above the average intelligence and fairly good mechanics.

(4) The consumption of coal and fresh water is considerable, and if the cranes and capstans were not required to work, but kept in a state of readiness, more coal and water would be consumed than for the hydraulic or electric plant, if they were kept idle in a similar manner, there being so many more boilers to keep under fire, viz., one to each crane and one stationary one to each group of capstans.

(5) The cranes are noisy, and, owing to great speed, have much vibration, with consequent wear and tear entailing a high cost for repairs, and danger of fire as the boilers are liable to emit sparks with the smoke.

(6) Generally they require to be supplied with coal from a store,

entailing labor and creating dirt on the quay. The machinery is more complicated than hydraulic, and partly exposed to the weather, in addition to which its wear and tear is considerable, and there are possible risks of explosion.

(7) The cost of working is higher than hydraulic or electric.

Hydraulic—Advantages.—(*a*) The power for working the plant being generated at a central station, the cost of working is reduced to a minimum, there being only one set of boilers to fire, and practically no fresh water is required beyond a few gallons daily.

(*b*) The machinery is quick in action, at least twice the speed of steam, and speed for speed for lifting, compared with electric, has a much less wear and tear, the cranes being capable of working 60 lifts per hour, or more if desired. At the trial of the large hydraulic 35-cwt. cranes made for the Tilbury Docks, 81 working lifts were made in 47 minutes, in which the goods were lifted out of a boat, slewed round and landed on the quay.

(*c*) Only one driver and stoker is necessary; a lower and cheaper class of men can work the cranes and capstan than is the case in steam-driven ones. It is, however, necessary to have one skilled mechanic to generally look after the work.

(*d*) If the plant should be required to stand idle for any length of time, only a very small amount of fuel would be consumed.

(*e*) Generally the machinery is noiseless, simple, clean, all protected from the weather, and has not much wear and tear; the cranes can be easily moved along the quay.

(*f*) Besides the hydraulic power being used to work the machinery already referred to, it would be available for elevating purposes in neighboring warehouses and for the extinction of fires by means of injector hydrants.

(*g*) The cost of working is less than by steam, but about the same as by electricity, but the upkeep is less than either.

Disadvantages.—(1) The initial cost is greater than for steam and slightly more than for electric cranes.

(2) In the case of a breakdown at the power-generating station, or failure of the mains, all the plant would be temporarily stopped. Although the author mentions this, he does not consider it at all likely to occur, nor does he know of any case where this has taken place; it is only necessary to have all details made amply strong.

Electric—Advantages.—(*a*) The power for working the plant being generated at a central station, the cost of generating is reduced to a minimum, etc., the same as in hydraulic.

(*b*) Machinery is quick in action, though not quite so quick as hydraulic.

(*c*) Only one driver and stoker is necessary, etc., the same as in a hydraulic plant.

(*d*) If the plant should be required to stand idle, etc., the cost is the same as for a hydraulic plant.

(*e*) Generally the machinery is fairly noiseless; it is cleaner than either steam and hydraulic, and can easily be arranged to be self-propelling along the quays.

(*f*) The power can also be used for lifting purposes in neighboring warehouses.

Electric—Disadvantages.—(1) Speed for speed of lifting, there would be more wear and tear than in the hydraulic system.

(2) In case of breakdown at the power-generating station or the failure of a main, all the plant would be temporarily stopped.

(3) The drivers of the cranes would have to be men of above the average intelligence.

(4) The upkeep would be slightly more than in the case of a hydraulic plant.

With regard to the cost of working the above systems, the author estimates them as follows:

APPROXIMATE ESTIMATE AFFECTING THE COST OF WORKING.

	Hydraulic and Electric.	Steam.
Coal for capstans, presuming steam in boilers is kept up all day and capstans ordinarily at work.	.....	20 to 25 cwt.
Coal consumed per day of 10 hours when working eight cranes continuously.	35 to 40 cwt. The greater would probably include the use of capstans.	70 to 80 cwt.
Water (fresh) consumed per day of 10 hours when working eight cranes continuously.	Practically *nil*.....	4 600 gallons.
Coal consumed when machinery standing idle and steam in boilers kept up.	1 cwt. per hour.....	½ cwt. per hour each crane, and ½ cwt per hour each capstan boiler.

From a general consideration of the above statements, it appears

from the author's point of view, that for a system such as is assumed, hydraulic would be the most suitable.

In connection with hoisting machinery and the motive power for working it, steam engines have now reached such a state of perfection that little more improvement in their designing and construction appears possible. Electric dynamos and motors can be made to reach 95% efficiency, so but little remains to economize upon here. The only remaining power dealt with in this paper is hydraulic, and in this room does exist for economizing the actuating water, and much should be possible in making further and enhanced economies. When a load is moved at a constant level and not against gravity, obviously no power would be required except for overcoming friction. Again, if it could be possible to so arrange the machinery and the work, that all loads should restore the water on which they descend into a reservoir, that is to say, should force the exhaust water previously used in the hydraulic cylinders as power-water into a reservoir, where it would be subjected to yielding pressure or utilized to assist the steam engines in pumping, it will be seen that a great gain would be possible. For example, say, in the case of a lift or jigger, if the same load was lifted as was lowered, no water should be used beyond that required for overcoming the friction of the machines and a method of working analogous to a regenerating system would be established.

This suggestion the author ventures to throw out for the consideration of engineers interested in this branch of mechanical science, and because he considers the present time so opportune for the inauguration of hydraulic power supplies in the several large cities in this great republic, and none more ripe and suitable than this vast one in which representatives from all parts of the world are now congregated. When buildings exist, as they do in Chicago, of such enormous elevation —the Rookery and Auditorium, as examples which by their height almost preclude the likelihood of their occupants and visitors walking down—much the same weight could be relied upon to be lowered as is raised, and the gain to be derived is at once evident.

For the purpose of supplying motive power to a city such as this hydraulic power is eminently suitable, as it could be used for passenger and goods lifts, and hoists for various pressing operations, the working of charging and discharging cranes along the large river frontage, for working the swing bridges, coal tips, railroad-crossing gates, grain elevators,

hydraulic riveting, raising and lowering of theater fireproof curtains, and would be available generally wherever mechanical motive power is required. When extremely high pressures should be necessary, a simple, well-known form of mechanism known as an "intensifier" gives the ready means of raising it to any amount. Lastly, and far from least, is the ready means the hydraulic system gives for the extinction of fires. In the face of all these advantages, the author suggests that this power would be the right and fit one for the particular purpose under review.

The London Power Company is allowed to draw 500 000 galls. daily from the River Thames free, on condition of returning it through the sewers, so flushing them. This is an extremely important point, and for flushing the sewers of this or other important cities during long spells of dry weather cannot be overrated.

One great advantage in the use of water supplied from a central station is, that the greater the demand, the better is the pressure maintained in the mains, and over 50% of the power at the generating station would be effective in work done on the consumer's premises. The author knows of a case where steam-power has been dispensed with (for pumping water for working lifts) and the public hydraulic power substituted, with a saving of 30% in the cost of working, and if this had been adopted at the outset the economy would have been greater.

Some objections may be raised that the water would be liable to freeze in very cold weather, but if the mains are laid well below the surface and covered, all buildings being heated in the winter, the author does not think any trouble would arise. Pressure raises the temperature of the freezing point. Apart from this, if desired, salt water could be used, and, as an actual case in point, the Barcelona Power Supply is all salt water.

Steam is out of the question as the motive power for such a case as is now being referred to, and electricity does not give facilities for adapting it to the multifarious processes alluded to, and, instead of being an aid in extinguishing fires, would rather tend to increase them, although certain advantages would exist in being able to work electric fire engines from electric mains which never require firing up and are always ready.

For occasional users of intermittent motive power, water, although at first glance it might not be considered suitable, would in practice be

found to be so, and to be very economical, particularly with motors such as the Rigg engine, or even what is known as the Armstrong type. The space occupied by the motors would be small, the speed slow, the wear and tear very small, and they would require no skilled attendant; besides being safe, no risks would exist of shocks, of explosions, and consequent loss of life. Of course, electricity would serve equally well as a motive power, and the hydraulic power is not put forward as a more suitable one, but simply to show that it could be used with many advantages over electricity, and certainly with more applications for its use. Probably if motive power was the chief public requirement, it would pay to install an electric service in addition to the hydraulic, as there would be room for both; and if qualified experts were called in to advise thereon, there is no doubt but that the right power would be apportioned to the right duty. For central supply stations, the motive power should be subdivided into small units, say, 150 to 200 H. P., depending on the size of the station and the fluctuation in the demand, and the engines should be of the vertical inverted triple-expansion condensing type; they give less wear and tear, and such as there is, is more even. Although not forming a part of the subject of this paper, to prevent misunderstanding the author would point out that the fire-extinguishing facilities given by a service of hydraulic power are not obtained by a wasteful expenditure of water, for the injector hydrants referred to act on the injector principle, viz., a very small jet of high-pressure water injected into the center of a large jet drawn from the public service mains increases the quantity so drawn, and intensifies the pressure of the latter on the delivery side of the injector so as to throw a jet equal to that of any fire engine.

As showing the cost of installing the hydraulic system in such a city as Chicago, the author now gives an estimate (based on English prices) for the plant, including buildings and 15 miles of mains.

Machinery.—Three sets of triple-expansion inverted steam surface condensing engines, with pressure pumps attached, each capable of pumping 150 000 gallons per day of 12 hours, against a pressure of 750 lbs. per square inch.

Four sets of three-throw pumps for raising the water into the settling and storage tanks having, for safety, 10% more capacity than the pressure pumps.

Six accumulators, three for station, three distributed; settling and

storage tanks; decanting pipes; 10 filters; air vessels; traveler; 3 tubular boilers; economizer; 8, 6, 5 and 4 in. pipe mains with valves.

Erecting the above and putting up engine buildings, chimney shafts and town accumulator houses.

Total cost.....£66 000.

To double the plant would add only about 60% of the cost.

The above figures do not include the cost of laying the mains, but the author states that this in English prices work out as under:

Eight-inch pipes per yard run, 17s. 6d.; 6-in., 15s.; 5-in., 13s. 9d.; 4-in., 12s. 6d

The actual cost of working the plant he estimates as follows:

Works—

1 engineer at.....	£3	0	0	per week.	
2 engine drivers at £2	4	0	0	"	
2 stokers at 26s.	2	12	0	"	
3 laborers at 22s.	3	6	0	"	
Total	12	18	0	"	
Say, 52 weeks at £13, per annum.....					£676 0 0

Coals—

For working the engines 24 hours per day, developing an average of 125 I. H. P.; 2.24 lbs. of coal per I. H. P. per hour = 3 tons, 300 days, 900 tons at 15s.....	674 0 0
Stores	100 0 0
	£1 450 0 0

APPENDIX No. 1.

Table of Results of Tests on Electric Hoisting Machinery.

Number of Tests.	Current supplied. Volts.	Current supplied. Ampères.	Counter E. M. F.	Effective volts.	Watts consumed	Weight lifted in tons.	Speed in feet per minute.	Horse-power in work done on weight.	E. H. P.	Efficiency of machine. Percent.	Remarks.
No. 1.	74	61	1.8361	73.1639	4462.99	.....	.....	.....	5.98	.. ....	Lifting light (chain and hook only).
Shop traveler.....	74	80	2.408	71.592	5727 36	6	2.69	1.094	7.67	13.5	Lifting weight.
	74	110	3.3110	70.689	7775.79	1.7	18.75	2.163	10.42	20·75	Lifting weight.
	75	111	3.3411	71.659	7954 14	1.7	19.62	2.264	10.66	21.23	Lifting weight.
	76	55	1.6555	74.3445	4080.95	6	....	.....	5.47	.....	Lowering.
Single motor.....	70	95	2.8595	67.1405	6378.35	6	.....	.....	8.55	.....	Traveling and lifting.
Shunt wound driving by band and belts.....	77	65	1.9565	75.0435	4877.83	6	.....	.....	6.54	.....	Traveling and lowering.
	79	65	1.9565	77.0435	5007.83	1.7	.....	.....	8.05	.....	Traveling and lifting.
	85	37	1.1137	83.8863	3103.79	1.7	.....	.....	4.16	.....	Traveling and lowering.
No. 2.	103	13.25	3.1	99.9	1323·67	.....	.....	.....	1.77	.....	Lifting light (chains and hook only).
Shop traveler.....	103	43.0	3.1	99.9	4295.7	7	7	3.326	5.76	57.7	Lifting weight.
	103	18.0	3.1	99.9	1798.2	7	.....	.....	2.41	.....	Lowering weight.
	103	8.4	3.1	99.9	839.2	.....	.....	.....	1.12	.....	Quite light, driving cones only.
Single shunt wound motor...	103	18.0	3.1	99.9	1798.2	.....	.....	.....	2.41	.....	Racking light.
	103	23.0	3.1	99.9	2297.7	7	.....	.....	3.08	.....	Racking loaded.
	103	18.0	3.1	.....	1798.2	.....	.....	.....	2.41	.....	Traveling light.
	103	23.0	3.1	99.9	2297.7	7	.....	.....	3.08	.....	Traveling loaded.
No. 3.											
Foundry hand traveler.....	110	22	.....	....	2110.0	.....	9.92	.....	2.83	.....	Lifting light (quick chain and hook only).
	103	20	.....	.....	1795.0	.....	3.41	.....	2.4	.....	Lifting light (slow chain and hook only).
(Converted) one-motor compound wound driving cross shaft by spur gearing...	90	76	.....	.....	5765.0	4	8.92	2.42	7.73	31.3	Lifting weights (quick).
	115	38	.....	.....	3782.0	4	3.41	.92	5 07	18.1	Lifting weights (slow).
	103	58	.....	... .	5109.0	9	3.27	1.99	6.85	29.05	Lifting weights.
	115	73	.....	.....	7150.0	13.5	3.32	3.04	9.59	31.7	Lifting weights.
	98	86	.....	.....	7091.0	18.5	2.97	3.73	9.95	37.5	Lifting weights.
No. 4.	200	15	.397	199.621	2994.31	.....	.....	.....	4.01	.....	Lifting light (ropes and hook only).
Southampton	200	95	2.403	197.597	18771.71	.75	200	10.17	25.16	40.4	Lifting weight.
	200	120	3.036	196.964	23635.68	1.0	200	13.57	31 68	42.8	Lifting weight.
Cranes.	200	140	3.542	196.458	27504.12	1.2	200	16.29	36.86	44.1	Lifting weight.
	200	160	4.048	195.952	31352.32	1.5	200	20.35	42.02	48.4	Lifting weight.
	200	· 7	1.498	198.502	1389.51	.....	.....	.....	1.86	.....	Slewing.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

632.

(Vol. XXIX—September, 1893.)

PRACTICAL AND ÆSTHETIC PRINCIPLES FOR THE LAYING OUT OF CITIES.

By J. STÜBBEN, Baurath and Assistant Burgomaster at Cologne, Germany.

Translated from the German by W. H. SEARLES, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The laying out of cities is accomplished in two ways: either in the course of additions to an existing settlement, by gradually extending the present roads and occasionally establishing new roads, as the number of buildings without reference to one another is increased; or, by establishing a general plan for new cities or parts thereof, according to which the intended construction is to be realized. The first way has been called the natural, and the last the artificial, method of laying out cities. This is a false definition, for it does not answer

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

the natural purpose to let the buildings string themselves together, regardless of plan; and it is not an artificial acquiescence, but practically a confirmed necessity, that the laying out or spreading out of a city should proceed upon the basis of a well-considered, comprehensive plan. It is more correct, therefore, to call the first method of city building the arbitrary, and the last the systematic. We have here to do only with the systematic or regulated laying out of cities.

The essential basis of regulated city-building is the establishment of future streets and places, and, consequently, of the plans for them. Here we regard not so much the technical improvement of the streets, or street-building proper, but rather a very skillful, consistent connection and complete network of streets, requisite for the traffic and growth of the city, the residence and joint life of the citizens. We are constrained, therefore, to develop the mere street plan into a building plan, or, further, into a city plan, *i. e.*, a design in which, out of the network of streets and building areas, are arranged all those constructive regulations as well, which are demanded for the life of the city.

The practical principles of such a plan of city construction relate to traffic, to building and to health. Moreover, æsthetic principles are to be followed which concern the construction of streets and public squares and their relation to edifices.

I. Practical Principles.

a. Traffic.—The streets and squares of a city have first of all to fulfill the demand that they accommodate the city traffic in the most perfect manner possible, for to serve the traffic is their most important duty.

The designer of a city plan has therefore to ascertain and establish, first of all, the real lines of traffic of the present time and of the future, so far as they can be foreseen. The first of these traffic lines are everywhere those which lead from the middle point of the city to the outskirts and the reverse. Their direction will be influenced by neighboring districts, railway stations, harbors, places of amusement and other attractive points of the vicinity. This gives rise to a net of radial lines or rays, as a glance at the map of an old city instantly teaches. The radial streets are on this account the first and most important in the design of a city plan to establish the members of the

network of city streets. They divide the city and suburbs into a series of sectors. As the size of these sectors increases toward the exterior, there arises the necessity of subdivision by means of radial lines of a second order, to the end that all the improved tracts may be conveniently reached from the midst of the city.

The second sort of traffic lines are such as serve the purpose of connecting the several sectors. They have in general a course like concentric circles around the central point of the city. These are the "ring streets," which are readily distinguished as of the first, second, or third order, etc., according to their signification on the city plan. In extended ground plans of a city the radial and ring streets often take on the form of longitudinal and cross streets.

Radial streets and ring streets always meet approximately perpendicularly. They divide the improved districts into lots of trapezoidal or approximately rectangular form. For obtaining proper building blocks a further division of these lots is necessary. These blocks are formed by using by streets which run approximately radial in one direction and circular in the other, so that the city plan will finally consist of a multitude of building blocks which altogether are more or less rectangular. Thus the traffic lines between two points which do not lie on the same street always consist of two legs at right angles to each other. From one extremity of the hypothenuse of a right-angled triangle to the other, one cannot go directly, but must always travel along the other two sides.

This does not correspond to the demands of traffic. The insertion of the hypothenuse is necessary, or, what is the same thing, the larger trapezoid or rectangular divisions must be traversed by diagonal streets before the subdivision by an approximately rectangular scheme of by streets is undertaken. The diagonal streets are to lie so that they will practically connect the chief focal points of the traffic directly with each other. These focal points are either given localities, such as railway stations, bridge terminals, landings, markets and the like, or they will be formed artificially by the junction of several streets. In the last instance occur the so-called "traffic places" as to which it is the problem to interpose an avenue from the one center of travel to the other.

The system of streets must be qualified to serve, not merely the ordinary foot, saddle and wagon travel, but in the design of the net-

work care should be taken that crowds may form in large numbers which street railways with animal or mechanical power may be able to take up.

The four kinds of streets, the radial, ring, diagonal and by streets, unless special reasons oppose, are so designed that existing roads and real-estate boundaries are followed if possible. This is only necessary for the existing highways comprehended in the built-up neighborhood; for other roads and property lines, the requirement is not essential.

The grades of the streets are to be made as convenient as possible for the traffic: the maximum to be according to local circumstances from 1 to 10%; the minimum, for the sake of drainage, 0.5 to 0.2 per cent. It is desirable that the streets should lie slightly above the general surface (say, 1 m.). Heights of 3 m. are ill-advised. Greater embankments and excavations are undesirable, because they increase the cost of improvements considerably, and require as a rule the grading of all adjoining property.

The width of streets should correspond to the expected traffic. It should be at least 10 m.; more than 40 m. is required only in the rarest instances. As to wider streets the claims of health and beauty give the proportions.

Transversely, the street is to be divided into at least one roadway and two raised sidewalks. A certain amount and kind of travel requires a special walk or promenade in the center of the street, a special bridle path or the division of the roadway for teams and equipages, giving rise to various cross-sections, and so much the more, when, for reasons of health and beauty, the streets are set out with rows of trees and flower beds.

Thus far we have considered only the traffic moving along city streets; but not less has the designer of city plans to regard those kinds of traffic which follow independent ways by, under, or over the city streets, viz.: Railroads (local and through), canals, wharves, docks, etc. Care should be taken to provide suitable space on the plan for the management of this sort of traffic adjoining the proper dépôts, harbors, landings and freight yards. To follow closely here the requisites of such a traffic-plan would exceed the bounds of the present problem, and would lead into technical domains which do not belong to city-building proper. Yet often it is a necessity to establish

the arrangements for the great traffic before the city map can be generally projected in detail.

b. The Buildings.—The meshes of the network of streets are as a rule termed the blocks. Their shape is rectangular, trapezoidal or triangular. The last form occurs especially along the diagonal streets. Various other shapes of blocks are occasionally found. The notion that acute-angled blocks are to be generally avoided on account of the difficulty of building on them, is incorrect; for, in the first place, conformity to the plan of traffic lines brings out sharp-angled blocks unconditionally, and, furthermore, the inconvenience in building is easily overcome, and indeed is availed of to bring about commercial and artistic advantages.

The sharp corners of the blocks are to be taken off. The amount to be cut off increases as the angle grows less, and should be large enough to provide for a façade on the corner. Instead of cutting away the corner it may be preferred to round it off; also, right-angled corners where a very large traffic occurs need to be cut off or rounded off. Generally, however, to accomplish this is neither necessary nor handsome. The cutting off of the obtuse angle of a block is only to be recommended in exceptional cases.

Within the blocks the boundary lines of the building lots should be drawn at right angles to the range lines of the streets bounding the same, so that in triangular, trapezoidal or irregular blocks buildings with oblique angles may occur only at street corners. Thus, oblique-angled property offers no difficulty in opposition to judicious and artistic building.

In case the lot lines are not perpendicular to the street, then, before building is allowed, the lines are to be so shifted by mutual exchange of equivalent areas that right-angled plots will everywhere obtain. If the change of lines cannot be obtained by the voluntary agreement of all owners, it becomes necessary to enforce the change by legal means, notwithstanding the opposition of individuals.

In right-angled blocks the depth is equal to the entire depth of two building lots abutting one another in the rear. Therefore the depth of lots, usual to the place or necessary for the future, fixes the depth of the blocks. Whatever the normal depth of a lot, the depth of the block is twice as great. In triangular or other blocks with diverging sides, the proportional depth is fixed by analogy with the foregoing.

The length of the blocks may amount to about 1½ to 2½ times their depth.

Factories and other industrial improvements require large blocks, say, 100 m. deep by 200 m. long, and should be so situated that the street and track connections with freight depots and harbors are easily obtained.

For private residences with gardens, medium-sized blocks are well adapted, say, 80 m. by 160 m. Property for rental and business houses which would be used as much as possible without gardens, may be judiciously divided into rather smaller blocks, say 60 m. by 120 m. Workmen's dwellings, finally, require smaller lots and, therefore, smaller blocks, say, 35 m. deep. The length can be increased to, say, 140 m. without disadvantage.

In dimensioning building blocks, however, there are to be considered the requirements, not merely of the individual, but in a greater degree of the public, that is, of the State, the parish and the corporation. Care is to be taken that blocks and parts of blocks be provided, suitable in position, shape and size for the erection of churches, high schools and common schools, for government buildings and courthouses, theaters, museums, concert and amusement halls, exchanges and banks, post and telegraph offices, markets and slaughter houses. If it is not possible for the city of the future to determine the size and place, collectively, of all the public improvements above mentioned, still the plan of the city should anticipate a sufficient number of building lots and blocks in convenient situations, which are proper to be used for public buildings as soon as the necessity arises. It is a mistake to refer the undertaking of such monumental and specific buildings haphazard to the later search anywhere for a half-way suitable place on a once-adopted building plan.

Many edifices, such as churches, theaters, museums, etc., require an open space, if not all around, at least on three sides. Many public buildings need a plaza even for traffic, while it is desirable to give others an axial position relative to the direction of a street, so that they may be readily found. All such claims are easily satisfied when laying out a plan of streets, but later only with difficulty and imperfectly.

c. Health.—Under the supposition that the climatic conditions of a country generally decide the settlement of a great mass of people in

one place, the first condition, in the interest of health, for the building or enlargement of a city is freedom from overflow and, therefore, a site above high water-mark, or a protection against flood. If the site is not free from overflow, protection must be brought about by artificial means, particularly by lowering the water surface, by raising the land surface, or by dikes with or without pumps.

A second condition is the dryness and cleanliness of the subsoil. It is important that the ground-water surface be not found in, nor occasionally rise into, those layers of sand which will be essentially changed or rendered impure in their condition under human settlement, and that, finally, the surface of the ground possess a form which renders an easy discharge of water possible. If the ground-water rises too high, it is prejudicial to health by inducing fermentation in the organic portions of the sandy stratum, prevents the use of cellar rooms, renders difficult the drainage of the surface and permits, through the absorption of waste material, the pollution, which is calculated to occasion danger to health, in water used for drinking and other purposes. In such cases before the soil upon a city plot is fit for use, the ground-water surface must be reduced, and its further rise prevented by a systematic subterranean canalization.

If the surface of the city ground generally shows a continual descent, the subterranean canalization can be, evidently, dispensed with for carrying off storm water. Here, however, as the city expands, the street gutters which have to carry off the rain water, require ever a larger cross-section; so, especially, the crossings of the streets with such gutters is very disturbing to the traffic, and so, for the draining of the surface, a network of subterranean channels soon proves to be necessary. Still, a gradual slope of the surface is important, because, in troughs and depressions of the ground without natural outlet, heavy rain storms may produce troublesome overflows notwithstanding the sewer system.

But, finally, the subterranean system of sewers is needful to carry off the domestic and industrial drainage and human waste material. As a rule, the combined system of sewers has shown itself the best for all three purposes described ; under certain circumstances, however, the arrangement of two or more separate sewer systems for ground-water, for rain, for house and industrial drainage, for fæcal deposits, may be judicious.

The general provision of good water for drinking, cooking and other uses is indispensable, as the subsoil of larger cities, even with the best endeavors to keep it pure, is undoubtedly incapable of furnishing drinking water. The combined provision of wholesome, faultless water is to be preferred to the separate provision of drinking water and water for other purposes.

The fourth requisite for health is light ; not merely the diffused light of the atmosphere, but also the direct light of the sunbeam. For the distribution of light, the direction and width of the streets is limited by the height and kind of buildings. The north and south direction of streets is itself advantageous, because it brings the unimpeded sunbeams to front or rear of both rows of houses. But it has the disadvantage that upon the streets at right angles—that is, east and west—the front of one row of buildings and the rear of the other are entirely deprived of the direct rays of the sun. The practical view shows, however, in accordance with the scientific theory, that in a system of right-angled or approximately right-angled streets, not the directions of north, south, east and west, but those intermediate directions of southwest, northeast and northwest, southeast are most favorable to direct sunlight. Diagonal streets in such a street system have a very favorable position from north to south, but diagonal streets from east to west have a correspondingly unfavorable position.

In reality, however, the considerations of traffic and buildings allow the designer of a city plan so little liberty that the orientation of the streets with regard to the sun is but seldom of decided significance in the regulation of a network of streets. Furthermore, it is feasible in the arrangement of the buildings to have regard to the sunshine. The restriction as to height of buildings and number of stories, the sufficient regulation of larger building spaces, the arrangement of ground plans of buildings, and particularly of the sort of additions and wings so that no living-rooms, or as few as possible, may open their windows only on the north side ; these are not in point to be further followed here; but if they will be duly considered in the requirements of the building police ordinances and in private building activity, it will be possible to shape dwellings satisfactorily in relation to sunshine, although the streets may not possess the most advantageous orientation.

Rooms without direct sunlight are, however, not to be altogether

avoided in general; they are even a necessity for certain industrial and artistic employments. For such rooms an abundant provision for diffused light of the atmosphere is so much the more important. This leads to the demand so to arrange the buildings that, at all events, in dwellings and other abodes, the rooms serving human needs may at least get a sight of a patch of sky under an angle of 45°. Thus, it may be guaranteed that the diffused rays of sunlight spread in the atmosphere will generally enter residences and living-rooms without being weakened and altered by reflection on the front of buildings or court-yard enclosures. But still this demand of not giving up the direct sunlight, which always presupposes that both in streets and in courts the height of buildings shall not practically exceed the distance between them, has thus far not been able to be realized in any city, through either the building directions of police or voluntary attention. In reference to this the effort has everywhere been, out of regard to cost, to enhance the usefulness of the building ground, in preference to studying hygiene. It is our duty, in the design of city building plans and building designs ever to bring into higher value the demands of public health with respect to supply of daylight.

For supplying the streets and buildings with artificial light by night, the illuminating gas, by reason of its consumption of oxygen and production of heat and of gases detrimental to health, does not wholly fulfill the hygienic requirement. The electric light, on this account, is to be preferred.

As a fifth hygienic requisite of city construction we have to denote care for the adequate amount of fresh air. And, indeed, there is needed a plentiful supply of air on the streets, in the blocks and within the buildings themselves. The aforesaid condition, that for the sake of light the height of buildings ought not practically to exceed the space between buildings, brings about on the streets and in the courts a sufficient airing. The streets and open courts, according to this, ought not to be less, or not materially less, than the houses are high ; indeed, according to the customary height of houses, a breadth of free space of at least 10, 15 or 20 m. is necessary. For streets in the newer portions of a city this demand is easily realized ; as for the courts, it is unfortunately frustrated in most cases by the value of the ground. But besides these most restricted dimensions of the air channels of a city, there are greater stores of air necessary, by the

help of which the change of air in the narrow channels can be consummated. Open squares serve this end, which interrupt the system of streets even at such places as the traffic alone does not call for; furthermore, blocks with interiors free from buildings, to contain gardens; and finally, districts of the city in which buildings will be allowed only with open spaces around them (country house districts) serve the same end. Such reservoirs of air can be formed by voluntary consent of property-owners; in default of which, they are to be provided compulsorily, by the official establishment of city-building plans, so that free plazas be kept open in the street system; that by retrograde building lines the interior of certain large blocks be kept free of buildings; and finally, that in designated parts of the city continuous rows of houses be interdicted.

In a particularly effective manner will the improvement of the air in the city be promoted by providing, on the established city plan, for a liberal setting out of trees. These serve, at the same time, a fifth hygienic interest, which consists in this—that the movement of the populace on pleasant shady paths will be made possible and easy. For setting out trees the streets and plazas are suitable, besides which care must be taken to provide for public gardens and parks and for promenades beyond them.

Streets with shade trees require a greater width than is necessary for traffic, or simply to provide light and air. The least width of a street planted with a row of trees on each sidewalk is about 20 m.; a width of 25 or 30 m. would be better. For planting a row of trees on a separate walk in the middle of the street a width of at least 25 m. is required; widths of 30 to 35 m. are better. Four or more rows of trees require still wider streets, so that the rows may be at least 6 m. apart. Instead of increasing the rows of trees it is often desirable to introduce front yards between the streets and buildings, or to lay out strips of garden plots with grass and ornamental shrubs within the street lines. It is self-evident that this sort of improvement is fit only for such parts of streets as can be dispensed with for traffic.

Just so the planting of open squares on the spaces which are required for traffic must not be demanded. Besides rows of trees and strips of grass there may be established whole gardens or small parks which either are open and to be crossed by all sorts of foot-travel, or are inclosed and serve only for quiet retreat. The latter enclosed spaces

are especially of great value to health. They come to be so by lessening street dust, by giving shade and by cleaning the atmosphere, and furthermore by this, that every such improvement affords opportunity for refreshment and recreation.

In addition to these, however, public parks of greater expanse are a hygienic necessity, wherein the people may take exercise in the open air. These are artificial landscapes of from 5 to 100 or more hectares in extent, which, under the titles of city gardens, people's gardens, burger parks, and the like, serve at the same time for bodily exercise (school play, football, croquet, lawn-tennis, skating, etc.), for the people's amusement and recreation.

The precise area which should be required in a city for tree planting is not easily specified. The local circumstances and means are in this respect extremely various. As a minimum it may be demanded that at least one-tenth of the city surface will be planted, and that at least 3 sq. m. of planted ground will fall to every inhabitant. The improvements outside the city limits are not included in this estimate.

The outside improvements, which ought to give the city population opportunity and inducement to further promenade or outing, are either connected pleasure grounds (*e. g.*, a natural or artificial grove) or streets and roads which will be beautified by rows of trees or landscape gardening wherever it is possible to lead to places of refreshment, or to afford a pretty outlook. The designer of a city building-plan has to provide for such hygienic arrangements in the suburbs with the greatest care.

A sixth essential of a city building-plan is, lastly, the judicious local disposition of such public or private arrangements as injure their neighborhood with regard to the health or pleasure of the inhabitants. For slaughter-houses and cattle-yards, for hospitals for the treatment of contagious diseases, and for churchyards, proper situations are to be provided. The carrying on of trades which through evaporations or noise bring danger or become burdensome is to be confined to appointed parts of the city.

II. Æsthetic Principles.

The building plan of a city in the wider sense, or the street plan in the narrower sense, ought not merely to satisfy the practical requirements of the traffic, of the building and of health; it ought also to be

laid out on æsthetic principles, *i. e.*, in such wise that it may give an impression of beauty in all its parts, or, what is the same thing, may awake in the beholder a disinterested satisfaction. As the fostering of beauty in all arts is the most eminent problem, so the beauty of the outward appearance in the art of building cities is of superlative importance. The art of city-building, which the city population everywhere comes in contact with, is more than any other branch of art practice an art for the people. If, with the cultivation of beauty, the associated influence of heart and soul be aimed at, we may anticipate from the æsthetic perfection of the building plan of a city, a rich and blessed influence upon the stratum of city population inclined to rudeness. At the same time, however, as well for the cultivated as for susceptible minds in general, it is a spring of pleasures and enjoyments. The considerations of the beautiful relate to the perfecting of the streets and squares in themselves, and to their relation to the buildings.

a. The Perfecting of the Streets and Squares.—The streets should not be too long. Too great length of street wearies the eye, wearies the spirit and awakens a feeling of discomfort. The danger of this unpleasant sensation begins as soon as the length of the straight streets exceeds 20 or 30 times their width. Should, however, a change of direction be undesirable for practical reasons, there remains the remedy against the tiresome effect of subjecting the street to variations in its width and cross-section.

For the regulation of streets, straight lines ought not to be exclusively employed. Gentle curves which conform to superficial outlines or to natural boundaries may produce fine effects in the form of the streets. It is not necessary that the two sides of a thoroughfare should be always exactly parallel; a pleasant effect may follow, from the irregular widths of streets, at the opening of squares, a junction with older parts of the city, or natural obstacles of ground. The bow-shaped avenue is preferable to the polygonal form, or strictly, a bow-like polygon of which single parts answer to the widths of the houses.

A street ought not to be conducted in straight lines over a summit; that is, convex changes of grade are to be avoided. The reason of the unbeautiful appearance of this sort of convex streets lies in the apparent sinking of the buildings, wagons and people beyond

the ridge of the street. Passing over a high point has to be accomplished by a bending of the street in plan and profile, the course of which the eye cannot follow beyond the ridge, or by means of breaking off the street at the summit. The interruption may be a vertical or a horizontal one ; a vertical in the form of a monument, a plantation, a fountain, or the like which the eye cannot see beyond ; a horizontal in the form of a crossing or dispersing place beyond which the direction of the street changes.

If the convex street is unhandsome, the concave profile creates on the contrary a special advantage. It affords to the street surface by day and by night a pleasing spectacle and may produce with artificial lights magnificent results.

The street surface ought not to be too wide, because the void does not satisfy the eye nor the mind. If the street surface cannot or should not be beautified with rows of trees and garden plots, a width is to be preferred restricted to traffic and health.

All portions of the street surface unnecessary to traffic are to be set out with ornamental plants or artificial ornaments. Rows of trees and garden spaces have been already mentioned. Artificial ornaments consist not merely in monuments, graceful statues, water-jets, flowing fountains, gate structures, arcades, and other works of architecture and sculptural art, but also in the tasteful and well-modeled improvements of requisite utility upon the streets, such as trading stalls, waiting rooms for street railways, places of convenience, columns for posters, fire-announcers, drinking stands, lamp-posts, candelabra, lanterns, street-signs, warning-boards, boxes for sweepings, enclosures, and tree-boxes. To the artistic sense and artistic gift of form, pleasure is given by all these, for the most part subordinate, objects, and thus they come to contribute to the pleasing and agreeable appearance of the street scene.

Finally, it is important in the improvement of the streets to provide for frequent change. This change should relate to street widths, the widths and arrangement of driveways and walks, the number and position of rows of trees, the artistic ornament, the garden surfaces in the streets and front yards, the kind of house-buildings (closed or open, high or low buildings). Every street, or at least every prominent street, should be handled and improved for itself individually, so that it may afford a characteristic appearance. The wearisome and

unhandsome uniformity under which so many modern streets suffer may be in this manner effectively avoided.

All the foregoing remarks upon perfecting the streets apply in greater measure to the public squares. They should not be too large, nor built exclusively on straight lines, nor have any summits; they should utilize the advantage of concave surfaces; they should be adorned with trees set out, with garden plots and artistic ornaments, so far as the traffic and the considerations in the following paragraph permit it to be done; and they should present an individual variety in their setting out.

The traffic squares decidedly require openings on all sides; their free surfaces serve the walking and driving travel. All other squares need a close-built frame of surroundings, because it is through this frame that the square is formed in an architectural sense; the wagon travel may be permitted around the border of the parks, but not across the open spaces of such squares.

b. The Relation of Streets and Squares to the Buildings.—The streets of the city are not merely for the purpose of serving the traffic, giving an opportunity for the improvement of real estate, and by their air spaces, plantations and accessories proving useful and beautiful, but they are also destined to bring our structures into agreeable position and effective grouping. The latter applies in an especial manner to monumental works of architecture and sculpture.

According to æsthetic laws, there are four different distances to be distinguished for viewing buildings and statues, viz., a distance equal to the approximate height of the work, which is specially suitable for observing the details of a structure; a distance equal to double the height, to view the whole work as a picture by itself; a distance equal to three times the height, in which the work, united with its surroundings, makes a part of the joint architectural idea, and a fourfold and greater distance, which only shows the grouping of masses and development of outlines, producing picturesque views of the city.

From which it follows, if a monumental edifice is to be erected within the ordinary street lines, the width of the street should not be less in any case than the height of the contemplated structure; but it is better to bring the street to one and a half or twice the measure. Should the latter be impracticable for the whole length of the street, the widening should occur directly in front of the structure, by

placing the structure back behind the street lines, in order to obtain front space and thus a distance of sight. Instead of setting back the structure, the corresponding place on the opposite side of the street can be set back, so that the open space is obtained on the other side of the street. In curved streets the concave side, to which the sight is always directed, is chosen for erecting monumental buildings, because more suitable than the more hidden convex side of the street.

But the appearance of a structure is more effective if in the original establishment, or the later completion of the plan of the city, the street system is so laid out that a monumental work forms the objective point (closing point) of a street, or of several streets; and furthermore, an elevated locality is assigned to such buildings. The axial and elevated erection of monumental buildings enriches and beautifies the appearance of the city, and serves at the same time a practical purpose, as it makes it easy to direct one's way in the network of streets.

We should beware of too frequently occurring faults in the axial arrangement of streets and monuments, namely, of exaggerating the distance of view, and of obstructing the traffic. According to the aforementioned æsthetic principles, the monument already begins to lose its architectural effectiveness at a distance of four times its height; there remains only the effect of picturesque masses and outlines. But these, too, lose their signification if by a very great increase of vista the scale of objects is too much reduced. Statues are, on this account, particularly unsuited to street intersections, and architectural works, as a rule, should not stand free to view at a greater distance than such as corresponds to 10 times the height. Also, a monument ought not to be of the kind to interrupt a line of traffic which would be compelled to go around the structure, in order to set forward again on the further side in the same direction as before. The monument should rather occupy the effective street termination at which a natural turning aside or separation of traffic occurs.

Still more than the shaping of streets does the improvement of public squares stand mutually related in artistic effect to buildings and monuments erected on or near the squares. The destination of squares as traffic areas, as air reservoirs, and as shaded places of recreation stands subordinate to the question how they may serve as a place

of setting up the more important works of architecture and monumental art. The erection follows so that the buildings and monuments take up a position either upon the area of the square, or they surround the square, or both kinds of erection are combined.

If the square is built up with a structure standing free all around, a space must be left open in front of the building at least of such width that it may serve as a plaza so as to offer the sufficient distance for observation. Here especially a distance equal to double the height is of importance. The other parts of the square have then merely a nearly neutral significance.

Instead of one front space, two or more are often arranged, in order —besides the front view—to bring into proper effect some other important aspects of the monument. With monuments of great extent this arrangement, which results in the division of the entire square into a group of squares, is specially judicious. In this connection care should be taken to secure the aspect of being in a closed frame to each one of the partial squares.

In a similar manner, too, should sculptured monuments, if they occupy a public square as a masterpiece, be so placed that the larger portion of the area should extend in front of the statue for its better observation, while the other parts of the square have a more restricted significance. The exceptions are such purely architectural monuments as columns, obelisks, fountains, etc., which are equally important on all sides. These may occupy the middle point of a square. Another kind of arrangement is adapted to an elongated place. It consists of a row of figures or monuments occupying the longitudinal axis, so that a masterpiece may adorn the middle point..

If the place is surrounded with several buildings, and has an open area, there arises the most distinguished creation of city construction. The most careful weighing of proportions is here especially important, in order to obtain the appropriate distances of observation. High structures come to stand at the ends, and low ones along the sides, of a place. A space of view of double the height is essential to comprehend the form of an edifice; a threefold distance is necessary, in order to enjoy a general view of a group of buildings. It does not require symmetry in a geometrical sense; but the buildings should so surround the place that an artistic balance may everywhere prevail, that the enclosure may appear complete, and that the outgoing streets may

not break up the design unfavorably. In many cases the breaks may be abolished or avoided by portals built over the street exits.

Also statuesque figures standing along the sides are suitable to complete and embellish the surroundings of the place. To every work can the just distance of view be thus afforded, while it contributes in general form to the artistic effect of the whole.

The combination plan of building upon and around the parts of a square is truly difficult, but still is accompanied by the loveliest artistic effects, if it fulfills the æsthetic considerations which govern the erection of building and monumental work in the various positions. It requires great exercise of a well-developed artistic feeling to strike the right thing. This feeling alone decides in a so-called picturesque, that is, irregular, laying out of a place and free groupings. These often occur, too, in modern, practically managed city plans where it depends upon bringing into harmony historical structures with new creations.

ABSTRACT.

I. Practical Principles.

a. The city traffic demands the laying out of radial, ring, diagonal and by streets, as well as business squares and focal points. A mere rectangular system is unfit for a street plan.

The laying out of street railways is to be regarded. The profile of the streets should be the flattest possible, but drained, the embankments not to be too high. Excavations are to be practically avoided. The width and cross-section of streets should answer generously to the amount and kind of traffic.

Also for traffic not done on the streets (railroad and water-way traffic) the layout of the city must have a care.

b. The blocks formed by the network of business streets are suitable for city construction. Sharp-angle corners are to be rounded off.

Within the blocks the property lines are to be swung into rectangular position by either voluntary exchange or legal compulsion.

The layout of the city has to provide blocks of different sizes in suitable places, such as are requisite for business operations, private houses, rented houses, stores and workmen's dwellings.

Also, blocks and parts of blocks are to be provided in suitable size and place for erecting public buildings.

c. For reasons of health, the city ground must be free from overflow, or protected; the soil must be kept dry and clean.

An underground system of sewers is indispensable to the removing of atmospheric precipitates, the domestic and industrial waste water, and human excreta.

General provision of good drinking water is necessary.

A sufficient provision of atmospheric light and of direct sunlight is to be served by a judicious orientation of the streets towards the cardinal points and a generous width of the streets; but, better still, by a rational arrangement of the habitations within the blocks. For night lighting the electric light is preferable to gas.

The providing of the city with fresh air requires, besides sufficient width of streets and size of yards, open squares in the street system and gardens in the building blocks; further, such districts as will allow only separate buildings to be erected; and, finally, shade trees on the streets, squares and separate parks. The plantations, consisting of rows of trees and garden levels, serve not merely to purify the air, but cause the city population to take bodily exercise, and afford recreation and refreshment.

The city layout has to provide special districts for industries injurious to health or annoying, or to lay down local restrictions.

II. Æsthetic Principles.

a. The elegant development of the streets requires the restriction of street-lengths, the variation of straight and curved street lines, the avoidance of convex and the preferring of concave changes of grade, the avoidance of street spaces all too wide and vacant, the setting out of the streets with horticultural and artistic decorations, and, furthermore, the individual handling of single streets, but not in a pattern-like way.

For the elegant development of places the same points of view are to be regarded. Convex shape of ground and excessive size of vacant levels are to be avoided; individuality of formation to be aimed at, and, so far as the design permits, a close-built frame of surroundings to be provided and the open spaces to be kept free from carriage roads across them.

b. For obtaining an elegant proportion between the streets and places on the one hand and the buildings on the other, the following

rules are useful: Choice of street-widths not narrower than the height of buildings; arrangement of spaces in front of important structures; preference of the concave side of streets; putting prominent structures in an elevated position and at the objective point of one or more streets, while avoiding, however, the embarrassment of traffic and exaggerated visual distances; furthermore, placing a structure upon an open square, so that a front space, or several parts of a square, suitably enclosed and of sufficient size, may be kept free for observation of the structure; placing one or more monumental buildings on or around an open place, so that suitable visual distance is everywhere afforded, the artistic equilibrium produced, the enclosure of the picture made complete, and its disintegration avoided.

Monuments of a figurative art are not to stand at the middle point of a square; this is permissible only for all-around homogeneous works of architectural art. Arranging them in rows on the longitudinal axis is seldom judicious, and standing them around the border is frequently so, and the bringing about of a correct distance for observation is necessary.

For the irregular arrangements of a picturesque kind, there is no other rule than artistic feeling.

NORTHEASTERN UNIVERSITY LIBRARIES
3 9358 00860140 0

NORTHEASTERN UNIVERSITY LIBRARIES
3 9358 00860140 0